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$C = \frac{5}{9}(F + 32$

$F = \frac{9}{5}C - 32$

AN ARITHMETIC OF
ELEMENTARY CHEMISTRY

BY

CHARLES TYNDALE EVANS
Master of Chemistry, The Hill School, Pottstown, Pa.

PRESS OF
THE NEW ERA PRINTING COMPANY
LANCASTER, PA.

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10 cu. cm. = .338 fl. oz.

1 millimeter = .0394 in

1 Cm. = [illegible]

EXERCISE I

METRIC SYSTEM AND EQUIVALENTS

1. How many grams in 5.867 kilograms?

2. Find the area in sq. cm. of a filter paper 5 cm. in diameter.

3. What is the capacity in liters of a spherical bulb 25 cm. in diameter?

4. How many kilograms of water at 4° C. could be put into a tank whose volume is 10 cubic decimeters?

5. How many kilograms of water at 4° C. will a tank 50 x 20 x 10 cm. hold?

6. What will a cubic meter of water at 4° C. weigh?

7. (*a*) How many liters of water in a cylindrical tank, 6 meters high and 3 meters in diameter? (*b*) What would be the weight of this water at 4° C.?

8. The height of a barometer is 29.8 in. Express this value in (*a*) mm.; (*b*) cm.

9. The ashes of a sheet of filter paper 2 meters long and 1.5 meters wide after ignition weighed 1.032 grams. What would the ashes of a pc. of similar filter paper 9 cm. in diameter weigh?

10. What length in cm. of platinum wire would be required to make a centigram rider, (i. e., a rider weighing one centigram), from a pc. of platinum wire, one foot of which weighs .15 gram?

11. (*a*) How many c.c. in one fl. oz.? (*b*) in one fl. qt.?

12. How many fl. oz. would a two liter bottle hold?

13. How many c.c. in 500 fl. oz.?

14. How many fl. oz. would a 100 c.c. graduate hold?

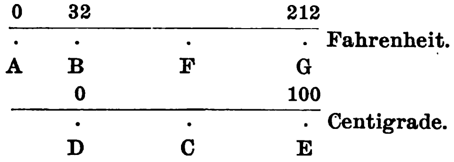
15. What would be the weight in kilograms of 2.5 gallons of water at 4° C.?

EXERCISE II

COMPARISON OF THERMOMETRIC SCALES

On the Centigrade scale the freezing and boiling points of water are marked 0 and 100 respectively; on the Fahrenheit scale these points are marked 32 and 212 respectively.

1. *To change from the Fahrenheit to the Centigrade scale, or vice versa.*



FORMULA 1

$$F^\circ - 32/9 = C^\circ/5.$$

Proof of Formula 1

Let F be the reading in degrees above zero on the Fahrenheit scale, and let C be the corresponding reading on the Centigrade scale, the position of the mercury in each case being due to the same source of heat.

Then, the degrees from B to G: degrees from D to E: : 180: 100. Since BF and DC are equal portions of BG and DE, $BF : DC : : 180 : 100$. BF (in degrees) $= F^\circ - 32$, and DC (in degrees) $= C^\circ$. Therefore, $F^\circ - 32 : 180 : : C^\circ : 100$. Or,

$$F^\circ - 32/180 = C^\circ/100 \text{ or } F^\circ - 32/9 = C^\circ/5.$$

2. *To change Centigrade readings to the Absolute scale.*

Absolute zero, at which there is no heat or molecular motion, is -273 when expressed in Centigrade degrees. Absolute temperatures (A) may be expressed by adding, algebraically, the number 273 to the given temperature expressed in Centigrade degrees.

For example, the freezing point of water on the Absolute scale is $0 + 273 = 273$; a temperature of -10 on the Centigrade scale is $-10 + 273 = 263$ on the Absolute scale.

FORMULA 2

$$A = C^\circ + 273.$$

T is generally used to express temperature on the Absolute scale. When t is used to designate Centigrade degrees, the formula becomes:

FORMULA 3

$$T = t^\circ + 273.$$

MODEL EXAMPLE 1 (*a*)

Change 68° F. to C°.

SOLUTION

$$F - 32/9 = C/5 \text{ (Formula 1)}; \; C = 20^\circ.$$

MODEL EXAMPLE 1 (*b*)

Change 15° C. to F°.

SOLUTION

$$F - 32/9 = C/5 \text{ (Formula 1)}; \; F = 59^\circ.$$

MODEL EXAMPLE 2

What is 10° C. on the Absolute Scale?

SOLUTION.

$$T = C^\circ + 273 \text{ (Formula 2)} = 10 + 273 = 283^\circ.$$

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Percentage of $CuSO_4$: 249.5 : 159.5 : : 100 : x; $x = 63.93\%$.
Percentage of H_2O : 249.5 : 90.0 : : 100 : y; $y = 36.07\%$.

MODEL EXAMPLE 6

What per cent of sulphur trioxide is there in $CaSO_4$?

SOLUTION

The formula may be written, $CaO \cdot SO_3$.

Molecular weight of $CaSO_4 = 136$
Molecular weight of $SO_3 = 80$
Per cent of SO_3: 136 : 80 : : 100 : x; $x = 58.82\%$.

PROBLEMS

Calculate the percentage compositions of the following:

36. Sulphuric acid, H_2SO_4.
37. Black oxide of iron, Fe_3O_4.
38. Sodium bicarbonate, $NaHCO_3$.
39. Lead nitrate, $Pb(NO_3)_2$.
40. Ammonium sulphate, $(NH_4)_2SO_4$.

---

41. Find the percentage of water in white vitriol, $ZnSO_4 \cdot 7H_2O$.
42. What is the percentage of iron in Fe_2O_3?
43. What is the percentage of sulphur in FeS_2?
44. Limestone, $CaCO_3$, will yield what per cent of quicklime, CaO?
45. What is the percentage of $CaSO_4$ in gypsum, $CaSO_4 \cdot 2H_2O$?
46. What is the percentage of magnesia, MgO, in magnesium pyrophosphate, $Mg_2P_2O_7$?
47. Find the percentage of sulphur trioxide, SO_3, in barium sulphate, $BaSO_4$.
48. What per cent of calcium carbonate must there be in a limestone which yields 55.22% of calcium oxide, CaO?
49. What per cent of iron oxide, Fe_2O_3, must an ore contain which shows 61.59% of metallic iron?
50. Determine the per cent of silica, SiO_2, in kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$.

Read.

EXERCISE V

LAW OF DEFINITE PROPORTIONS

The Law of Definite Proportions may be divided into two parts, viz.: (1) The Law of Definite Weight; (2) The Law of Definite Volume.

3. *The Law of Definite Weight.*

(*a*) Any given chemical compound always contains the same elements in the same proportion by weight.

For example, sodium chloride, NaCl, always contains Na and Cl in the ratio of 23 : 35.5 by weight. If a compound should contain Na and Cl in proportions differing markedly from this ratio, it would have different properties and be an entirely different substance.

(*b*) The Law of Definite Weight means also that, when reactions take place between two or more substances to form definite products, the weights of the substances used and formed bear absolutely unvarying ratios to each other.

Thus, when hydrochloric acid, HCl, acts on zinc, Zn, the reaction takes place according to the following equation:

$$\begin{array}{ccccccc} Zn & + & 2HCl & = & ZnCl_2 & + & H_2 \\ 65.5 & & 73 & & 136.5 & & 2 \end{array}$$

The weights of the zinc and hydrochloric acid taken must have the ratio of 65.5 : 73, and the ratios of zinc chloride and hydrogen obtained will always be 136.5 : 2. If weights of zinc and hydrochloric acid having a different ratio should be taken, a portion of one of the substances would not enter into combination, and the quantities of zinc chloride and hydrogen formed would be entirely dependent upon the ratio stated above.

Suppose 70 grams of Zn and 75 grams of HCl are taken. Then only 67.6 grams of zinc would enter into combination with the hydrochloric acid, as $67.6 : 75 = 65.5 : 73$, and 2.4 grams of zinc would remain uncombined. In this case, $75 : x = 73 : 136.5$, and $x = 140.24$ g. of zinc chloride would be formed.

4. *The Law of Definite Volume* will be illustrated and applied in Exercise VI.

Model Example 7

What weight of oxygen can be obtained from 108 grams of mercuric oxide, HgO? At. wts.: Hg, 200; O, 16.

Solution

$$\begin{array}{lrr} & 2HgO = 2Hg + & O_2 \\ \text{Combining weights} \ldots\ldots\ldots & 432 & 32 \\ \text{Actual weights} \ldots\ldots\ldots\ldots\ldots & 108 & x \end{array}$$

To get the weight of the oxygen: $432/32 = 108/x$; $x = 8$ grams.

Model Example 8

(*a*) How much common salt must be used to make 292 grams of hydrochloric acid gas?

(*b*) What will be the weights of the other substances in the reaction? At. wts.: Cl, 35.5; Na, 23; S, 32; O, 16; H, 1.

Solution

$$\begin{array}{lccc} & 2NaCl & + & H_2SO_4 \\ \text{Combining weights} & 2(23 + 35.5) & & (2 + 32 + 64) \\ & 117 & & 98 \\ \text{Actual weights} \ldots\ldots & x & & y \end{array}$$

$$\begin{array}{cccc} = & Na_2SO_4 & + & 2HCl \\ & (46 + 32 + 64) & & 2(1 + 35.5) \\ & 142 & & 73 \\ & z & & 292 \end{array}$$

Weight of $NaCl$: $117/73 = x/292$; $x = 468$ grams.
Weight of H_2SO_4: $98/73 = y/292$; $y = 392$ grams.
Weight of Na_2SO_4: $142/73 = z/292$; $z = 568$ grams.

PROBLEMS

51. What weight of oxygen can be obtained from 245 grams of potassium chlorate?

$$2KClO_3 = 2KCl + 3O_2$$

52. What weight of hydrochloric acid will dissolve 10 grams of zinc?

$$Zn + 2HCl = ZnCl_2 + H_2$$

53. What weight of carbon dioxide will be formed by burning 5 grams of charcoal in oxygen?

$$C + O_2 = CO_2$$

54. How many grams of oxide of iron will result from the combustion of 2 grams of iron in oxygen?

$$3Fe + 2O_2 = Fe_3O_4$$

55. What weight of hydrogen will be set free by passing steam over 21 grams of highly heated iron?

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2$$

Model Example 9 (*a*)

What weight of zinc will be dissolved by 200 grams of a solution of sulphuric acid containing 24.5% by weight of the acid? At. wts.: Zn, 65.5; S, 32; O, 16; H, 1.

Solution

Since 24.5% or .245 of the solution is H_2SO_4, the actual amount of the acid available is 200 x .245 = 49 grams.

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

Combining weights 65.5 98
Actual weights .... x 49

Weight of zinc dissolved: $65.5/98 = x/49$; $x = 32.75$ grams.

Model Example 9 (*b*)

How many grams of a 20% solution of nitric acid will be neutralized by 3.5 grams of ammonium hydroxide? At. wts.: O, 16; N, 14; H, 1.

SOLUTION

$$NH_4OH + HNO_3 = NH_4NO_3 + H_2O$$

	NH_4OH	HNO_3
Combining weights..	35	63
Actual weights	3.5	x

Weight of HNO_3 required: $35/63 = 3.5/x$; $x = 6.3$ grams.

The 6.3 grams represent 20% or .20 of the weight of the solution required. Therefore, the weight of the solution of HNO_3 must be $6.3/.20 = 31$ grams.

---

56. How many grams of caustic soda in solution will be neutralized by a 25% solution of hydrochloric acid weighing 7.3 grams?

$$NaOH + HCl = NaCl + H_2O$$

57. (*a*) What weight of common salt will make 15 grams of chlorine?

(*b*) What weight of a 50% solution of sulphuric acid must be used?

$$2NaCl + 2H_2SO_4 + MnO_2 = MnSO_4 + Na_2SO_4 + 2H_2O + Cl_2$$

58. (*a*) How much black oxide of manganese must be heated to furnish 144 grams of oxygen? (*b*) How much mangano-manganic oxide will be formed?

$$3MnO_2 = Mn_3O_4 + O_2$$

MODEL EXAMPLE 10

By what factor must the weight of the $Mg_2P_2O_7$ obtained in the analysis of a limestone be multiplied to show the weight of (*a*) the MgO, (*b*) the $MgCO_3$, in the substance?

SOLUTION

Mol. wt. of $Mg_2P_2O_7 = 223$.

Mol. wt. of $MgO = 40.5$.

Mol. wt. of $MgCO_3 = 84.5$.

(*a*) $223/40.5 = 1/x$; $x = .1816$.

(*b*) $223/84.5 = 1/y$; $y = .3789$.

59. By what factor must the weight of the CaO be multiplied to show the weight of the $CaCO_3$ in a substance?

60. By what factor must the weight of NaCl obtained in the analysis of a clay be multiplied to represent the Na_2O present?

61. In an analysis 1.0000 gram of a substance gave .8212 gram of Fe_2O_3. (*a*) By what factor must the weight of the Fe_2O_3 be multiplied to get the Fe? (*b*) What is the percentage of Fe in the substance?

62. How many grams of ammonia gas can be made from 107 grams of ammonium chloride by the action of calcium hydroxide?

$$2NH_4Cl + Ca(OH)_2 = CaCl_2 + 2NH_3 + 2H_2O$$

63. How much ammonium nitrate must be used to make 32 grams of "laughing gas"?

$$NH_4NO_3 = 2H_2O + N_2O$$

64. What weight of caustic potash will be neutralized by a solution containing 24.5 grams of sulphuric acid?

$$2KOH + H_2SO_4 = K_2SO_4 + 2H_2O$$

65. (*a*) How much copper nitrate will be formed by dissolving 12.7 grams of copper in nitric acid? (*b*) What will be the weights of the other substances formed in the reaction?

$$3Cu + 8HNO_3 = 3Cu(NO_3)_2 + 2NO + 4H_2O$$

MODEL EXAMPLE 11

How much silver chloride can be made from 12.2 grams of crystallized barium chloride, $BaCl_2 \cdot 2H_2O$? At. wts.: Ba, 137; Cl, 35.5; O, 16; H, 1.

SOLUTION

$BaCl_2 \cdot 2H_2O + 2AgNO_3$

Combining weights. $(137 + 71 + 36)$

244

Actual weights.... 12.2

$= \quad 2AgCl \quad + Ba(No_3)_2 + 2H_2O$

$2(108 + 35.5)$

287

x

Weight of silver chloride: $244/287 = 12.2/x$; $x = 14.35$ grams.

MODEL EXAMPLE 12

What quantities of ammonium sulphate, $(NH_4)_2SO_4$, and aluminum sulphate, $Al_2(SO_4)_3\cdot 18H_2O$, must be taken to make 151 grams of ammonium alum, $(NH_4)_2SO_4\cdot Al_2(SO_4)_3\cdot 24H_2O$?

SOLUTION

	$(NH_4)_2SO_4$ +	$Al_2(SO_4)_3\cdot 18H_2O + 6H_2O$	$= (NH_4)_2SO_4\cdot Al_2(SO_4)_3\cdot 24H_2O$
Combining weights.	132	666	906
Actual weights	x	y	151

Weight of ammonium sulphate: $132/906 = x/151$; $x = 22$ grams.

Weight of aluminum sulphate: $666/906 = y/151$; $y = 111$ grams.

66. How much potassium sulphate can be made from 10 kilograms of kieserite, $MgSO_4\cdot H_2O$?

$$MgSO_4\cdot H_2O + 2KCl = K_2SO_4 + MgCl_2 + H_2O$$

67. (*a*) How much bismuth nitrate, $Bi(NO_3)_3\cdot 10H_2O$, would crystallize from a solution of 10.4 grams of bismuth in nitric acid? (*b*) What weight of 30% nitric acid would be needed?

$$Bi + 4HNO_3 + 8H_2O = Bi(NO_3)_3\cdot 10H_2O + NO.$$

68. What weight of platinum would be required to make 10 grams of chloro-platinic acid, $H_2PtCl_6\cdot 6H_2O$?

$$Pt + 2Cl_2 + 2HCl + 6H_2O = H_2PtCl_6\cdot 6H_2O.$$

69. How many grams each of (*a*) green vitriol, $FeSO_4 7H_2O$, and of (*b*) ammonium sulphate, $(NH_4)_2SO_4$, would be required to make 56 grams of ferrous ammonium sulphate, $FeSO_4\cdot (NH_4)_2SO_4\cdot 6H_2O$?

$$FeSO_4\cdot 7H_2O + (NH_4)_2SO_4 = FeSO_4(NH_4)_2SO_4\cdot 6H_2O + H_2O.$$

70. (*a*) How many grams of ammonium oxalate, $(NH_4)_2C_2O_4\cdot H_2O$, can be made from 12.6 grams of oxalic acid? (*b*) How

many grams of ammonium hydroxide, containing 20% by weight of NH_3, would be needed?

$$C_2H_2O_4 \cdot 2H_2O + 2NH_4OH = (NH_4)_2C_2O_4 \cdot H_2O + 3H_2O$$

71. (*a*) What weight of blue vitriol, $CuSO_4 \cdot 5H_2O$, can be made from 25.4 grams of copper? (*b*) How many grams of 96% sulphuric acid would be necessary?

$$Cu + 2H_2SO_4 + 3H_2O = CuSO_4 \cdot 5H_2O + SO_2$$

72. (*a*) How much potassium sulphate, K_2SO_4, and (*b*) how much aluminum sulphate, $Al_2(SO_4)_3 \cdot 18H_2O$, will be required to make 94.8 grams of potassium alum, $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$?

$$K_2SO_4 + Al_2(SO_4)_3 \cdot 18H_2O + 6H_2O = K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$$

73. How much crystallized manganese chloride, $MnCl_2 \cdot 4H_2O$, could be obtained by the action of hydrochloric acid on 43.5 grams of manganese dioxide?

$$MnO_2 + 4HCl + 2H_2O = MnCl_2 \cdot 4H_2O + Cl_2.$$

74. What weight of sal soda, $Na_2CO_3 \cdot 10H_2O$, must be used in making 34 grams of sodium acetate, $NaC_2H_3O_2 \cdot 3H_2O$?

$$Na_2CO_3 \cdot 10H_2O + 2HC_2H_3O_2 = 2NaC_2H_3O_2 \cdot 3H_2O + 5H_2O + CO_2$$

75. What weights of (*a*) crystallized disodium orthophosphate, $HNa_2PO_4 \cdot 12H_2O$, and of (*b*) ammonium chloride, NH_4Cl, will be required to yield 41.8 grams of microcosmic salt, $HNaNH_4PO_4 \cdot 4H_2O$?

$$HNa_2PO_4 \cdot 12H_2O + NH_4Cl = HNaNH_4PO_4 \cdot 4H_2O + NaCl + 8H_2O$$

EXERCISE VI

LAW OF DEFINITE VOLUMES

5. *The Law of Definite Volume.*

Any gaseous compound or any other compound formed by the combination of gases always contains the same elements in the same ratio by volume.

To illustrate, hydrochloric acid, HCl, is composed of equal volumes of hydrogen and chlorine, and a substance having the properties of hydrochloric acid can be formed only by taking these gases in equal proportions.

6. *Gay-Lussac's Law of Volumes.*

When reactions take place between two or more substances in the gaseous state, the volumes of the substances used and formed bear a definite relation to each other by volume.

ILLUSTRATIONS

One volume of hydrogen and one volume of chlorine will form two volumes of hydrochloric acid.

Two volumes of hydrogen and one volume of oxygen will form two volumes of water vapor.

When two volumes of ammonia gas are decomposed, they yield one volume of hydrogen and three volumes of nitrogen.

7. *Avogadro's Hypothesis.*

Equal volumes of all gases under the same conditions of temperature and pressure contain the same number of molecules.

This indicates that the volumes occupied by all gaseous molecules are equal, and, therefore, *the ratio between the molecules* will be *the ratio of the volumes.*

For example, the combustion of carbon monoxide may be represented by the equation: $\underset{2}{2CO} + \underset{1}{O_2} = \underset{2}{2CO_2}$. This means that 2 molecules of CO and 1 molecule of O form 2 molecules of CO_2. Since all molecular volumes are equal, the *unit* volumes are 2, 1 and 2 respectively, no matter whether the volumes be liters, cc., or any other unit.

MODEL EXAMPLE 13 (*a*)

How many cu. ft. of carbon dioxide will be formed by burning 1000 cu. ft. of carbon monoxide?

SOLUTION

$$2CO + O_2 = 2CO_2$$

Ratio of the molecules......	2	1	2
Ratio of the volumes........	2	1	2
Actual volumes	1000		x

Volume of CO_2: $2/2 = 1000/x$; $x = 1000$ cu ft.

MODEL EXAMPLE 13 (*b*)

(*a*) How many liters of acetylene gas will be burned by 10 liters of oxygen, and (*b*) how much carbon dioxide will be formed?

SOLUTION

$$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O$$

Ratio of molecules ..	2	5	4
Ratio of volumes	2	5	4
Actual volumes	x	10	y

Volume of C_2H_2: $2/5 = x/10$; $x = 4$ liters.

Volume of CO_2: $5/4 = 10/y$; $y = 8$ liters.

MODEL EXAMPLE 14

How many cu. ft. of air containing 20% of oxygen would be required to burn 1000 cu. ft. of natural gas of the following composition: marsh gas, CH_4, 60%; hydrogen, 29%; carbon monoxide, .5%; oxygen, .75%; ethylene, C_2H_4, 1%; ethane, C_2H_6, 8%.

SOLUTION

Volume of CH_4 to be burned: $1000 \times .60$ (60%) = 600 cu. ft.

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

Ratio of molecules and volumes..	1	2
Actual volumes	600	x

Volume of O required to burn the CH_4: $1/2 = 600/x$;
$x = 1200$ cu. ft.

Volume of H to be burned: 1000 x .29 (29%) = 290 cu. ft.

$$2H_2 + O_2 = 2H_2O$$

$$\begin{array}{cc} 2 & 1 \\ 290 & y \end{array}$$

Volume of O required to burn the H: $2/1 = 290/y$;
$y = 145$ cu. ft.

Volume of CO to be burned: 1000 x .005 (.5%) = 5 cu. ft.

$$2CO + O_2 = 2CO_2$$

$$\begin{array}{cc} 2 & 1 \\ 5 & z \end{array}$$

Volume of O required to burn the CO: $2/1 = 5/z$;
$z = 2.5$ cu. ft.

Volume of C_2H_4 to be burned: 1000 x .01 (1%) = 10 cu. ft.

$$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$$

$$\begin{array}{cc} 1 & 3 \\ 10 & x' \end{array}$$

Volume of O required to burn the C_2H_4: $1/3 = 10/x'$;
$x' = 30$ cu. ft.

Volume of C_2H_6 to be burned: 1000 x .08 (8%) = 80 cu. ft.

$$2C_2H_6 + 7O_2 = 4CO_2 + 6H_2O$$

$$\begin{array}{cc} 2 & 7 \\ 80 & y' \end{array}$$

Volume of O required to burn the C_2H_6: $2/7 = 80/y'$;
$y' = 280$ cu. ft.

Total O required = 1200 + 145 + 2.5 + 30 + 280 = 1657.5 cu. ft.
O in the gas = 1000 x .0075 (.75%) = 7.5 cu. ft.
O required = 1650.0 cu. ft.

Since the O in the air is only 20% or .20 of the total volume, the volume of air required is 1650/.20 = 8250 cu. ft.

MODEL EXAMPLE 15

How much hydrogen will be burned, and what will be the final composition of the gases resulting from the ignition of 23.2 c.c. of hydrogen mixed with 50 c.c. of air which contains

21% by volume of oxygen, all being kept above the boiling point of water and under the same conditions of temperature and pressure?

SOLUTION

	$2H_2 +$	$O_2 =$	$2H_2O$
Ratio of molecules…………	2	1	2
Ratio of volumes…………	2	1	2
Actual volumes …………	x	10.5	y

(There are 50 c.c. of air, .21 (21%) of which is oxygen; therefore, there are $50 \times .21 = 10.5$ c.c. of oxygen available.)

Volume of H burned: $2/1 = x/10.5$; $x = 21$ c.c.
Volume of H_2O formed: $1/2 = 10.5/y$; $y = 21$ c.c.

There will be finally:

Water vapor ………	21 c.c.	
Unburned hydrogen ..	2.2 c.c.	(23.2 — 21.0)
Unaffected air ………	39.5 c.c.	(50 — 10.5)
Total ………………	62.7 c.c.	

PROBLEMS

(Conditions of temperature and pressure remain constant)

76. (*a*) How many liters of oxygen will be required to burn 10 liters of marsh gas, and (*b*) how much carbon dioxide will be formed under the same conditions of temperature and pressure?

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

77. How many liters of carbon dioxide will be formed by the burning of 5 liters of carbon monoxide?

$$2CO + O_2 = 2CO_2$$

78. How many c.c. of ammonia gas will result from the combination of 100 c.c. of nitrogen and 300 c.c. of hydrogen if only 98% of the gases combine?

$$N_2 + 3H_2 = 2NH_3$$

79. How many cu. ft. of hydrogen and oxygen will result from the decomposition of 1,000 cu. ft. of steam?

$$2H_2O = 2H_2 + O_2$$

80. If a gas contain merely hydrogen and carbon monoxide in equal proportions by volume, how many cu. ft. of the gas will be burned by 2,500 cu. ft. of air, 20% of whose volume is oxygen?

$$CO + H_2 + O_2 = CO_2 + H_2O$$

81. How many molecules of chlorine will combine with 200,000 molecules of hydrogen?

$$H_2 + Cl_2 = 2HCl$$

82. How many c.c. of oxygen will be set free from 1,200 c.c. of ozone?

$$2O_3 = 3O_2$$

83. How many atoms of nitrogen and of hydrogen would form 1,000,000 molecules of ammonia gas?

$$3H_2 + N_2 = 2NH_3$$

84. How many c.c. of nitric acid vapor must be decomposed to set free 500 c.c. of oxygen?

$$4HNO_3 = 2H_2O + 4NO_2 + O_2$$

85. 17.8 c.c. of air were mixed with enough hydrogen to make a volume of 35 c.c. and the mixture was ignited. The resulting volume was 24.2 c.c. What per cent of oxygen by volume did the air contain? (It is assumed that the steam is changed to water, and its volume *is not included in the final volume.*)

86. What volumes of carbon dioxide and water vapor will be formed when 1,000 cu. ft. of a coal gas of the following combustible substances are burned: hydrogen, 48%; marsh gas, 38%; ethylene, 5%; carbon monoxide, 7%?

87. What volume of oxygen will be required to burn 10,000 cu. ft. of a natural gas of the following composition: hy-

drogen, 22.5%; marsh gas, 60%; ethylene, 7%; carbon dioxide, 2.5%; oxygen, 0.5%; nitrogen, 7.5%?

88. One liter of chlorine is mixed with 1.5 liters of hydrogen. (*a*) How much HCl gas will result? (*b*) Which gas remains in excess, and what will be its volume?

89. How many cu. meters of air containing 21% of oxygen by volume will be required to make 500 cu. meters of nitrogen peroxide according to the following equation: $2NO + O_2 = 2NO_2$ (Birkeland and Eyde Process).

90. (*a*) How many cu. ft. of air containing 21% of oxygen by volume will be required to burn 100,000 cu. ft. of the following mixture: hydrogen, 15%; marsh gas, 50%; carbon monoxide, 35%.

(*b*) What will be the volumes of the products resulting, assuming the H_2O to be in the form of vapor?

EXERCISE VII

VAPOR DENSITY AND MOLECULAR WEIGHTS

8. The Vapor Density of a gas is the ratio between the weight of a definite volume of the gas and the weight of an equal volume of hydrogen taken at the same temperature and pressure.

For example, if one liter of oxygen weighs 1.43 grams, and a liter of hydrogen weighs .0899 gram under the same conditions, the vapor density (V.D.) of the oxygen is 1.43/.0899 = 16.

Note.—The vapor density of a gas is often defined as the *specific gravity of the gas referred to hydrogen.*

FORMULA 4

The vapor density (V.D.) of a gas is equal to one-half of its molecular weight (M.W.), that is,

$$V.D. = M.W./2$$

PROOF OF FORMULA

The molecular weight of hydrogen (H_2) is 2. The ratio between the *weights of equal volumes of all gases* is the ratio *between the relative weights of their molecules* (Section 7). When the molecular weight of hydrogen is 2, the vapor density of any gas is equal to the molecular weight of the gas divided by 2 (M.W./2).

MODEL EXAMPLE 16

(*a*) What is the vapor density of carbon dioxide, CO_2?

(*b*) What must be the molecular weight of a gas one liter of which weighs 1.98 grams under standard conditions of temperature and pressure?

SOLUTION

(*a*) Molecular weight (M.W.) of $CO_2 = 44$. Therefore, V.D. = M.W./2 = 22. (Formula 4.)

(*b*) By Section 8, V.D. = 1.98/.09 = 22. Since V.D. = M.W./2, 22 = M.W./2, and M.W. = 44.

9. Often the vapor density of a gas is referred to air instead of hydrogen as the unit.

Air, on the average, is approximately 14.44 times as heavy as hydrogen. Therefore, when the density of a gas is given in terms of air, this number must be multiplied by 14.44 to get the density in terms of hydrogen.

FORMULA 5

$D = \text{M.W.}/28.88$, where D = density referred to air as the unit.

PROOF

$\text{V.D.} = D \times 14.44$ (Section 9).

$\text{V.D.} = \text{M.W.}/2$. (Formula 4.) Therefore,

$$D = \text{M.W.}/2 \times 14.44 = \text{M.W.}/28.88.$$

MODEL EXAMPLE 17

(*a*) What is the density of carbon dioxide, CO_2, referred to air?

(*b*) A gas has the density of 1.66 compared with air. What is its approximate molecular weight?

SOLUTION

(*a*) M.W. of $CO_2 = 44$. $D =$ M.W./28.88. (Formula 5.)
$D = 44/28.88 = 1.5$.
(*b*) $D =$ M.W./28.88; $1.66 =$ M.W./28.88;
therefore, M.W. $= 48$.

10. Inasmuch as the atomic weight of oxygen is often taken as exactly 16 in computing atomic weights instead of assuming the atomic weight of hydrogen to be 1, the densities of gases are also referred to oxygen.

Since the molecular formula of oxygen is O_2, the molecular weight of O is 32. Therefore, the density of the gas in terms of oxygen must be multiplied by 16 to get the density in terms of hydrogen, since the vapor density of O is 16. (Formula 4.)

FORMULA 6

$D' =$ M.W./32, where D' is the density referred to oxygen.

PROOF

V.D. $= D' \times 16$. (Section 10.) V.D. $=$ M.W./2 (Formula 4).
Therefore, $D' \times 16 =$ M.W./2, and $D' =$ M.W./32.

MODEL EXAMPLE 18

(*a*) What is the density of carbon dioxide, CO_2, in terms of oxygen?

(*b*) If a gas has the density of 1.375 compared with oxygen, what is its molecular weight?

SOLUTION

(*a*) $D' =$ M.W./32. (Formula 6.) M.W. of $CO_2 = 44$.
Therefore, $D' = 44/32 = 1.375$.
(*b*) $D' =$ M.W./32. $1.375 =$ M.W./32, and M.W. $= 44$.

PROBLEMS

91. Calculate the vapor densities of the following gases: (*a*) water vapor, (*b*) ammonia gas, (*c*) carbon monoxide, (*d*) nitric oxide, (*e*) nitrous oxide.

92. (*a*) What is the molecular weight of a substance, the vapor density of which is 38?

(*b*) The specific gravity of a gas with reference to hydrogen is 8.5. What is its molecular weight?

93. (*a*) If the formula of air were N_4O, what would one liter of air weigh?

(*b*) A liter of a gas weighs 13.2275 grams when a liter of oxygen weighs 1.43 grams. What is the molecular weight of the unknown gas?

94. (*a*) The molecular weights of two compounds are 16 and 78. What is the ratio of their vapor densities?

(*b*) What is the volume of 7.65 grams of a gas whose vapor density is 8.5 when a liter of hydrogen weighs .09 gram?

95. (*a*) A liter of carbon dioxide weighs 1.26 grams. What is its density with reference to (i) hydrogen, (ii) air?

(*b*) If a gas has a density of 2.45 as compared with air, what is its approximate molecular weight?

EXERCISE VIII

WEIGHTS AND VOLUMES OF GASES

11. When a gas is measured at 0° C. and under 760 mm. or 76 cm. pressure, it is said to be measured under *standard* or *normal* conditions of temperature and pressure.

(*a*) A pressure of 760 mm. means that the height of the column of mercury in a mercury barometer is 760 mm. or 76 cm.

(*b*) "Standard or normal conditions of temperature and pressure" is often abbreviated to S.T.P. or N.T.P.

12. A *gram-molecule* or gram-molecular-weight (gr. mol. wt.) of a substance is its *molecular weight* expressed in grams. A gram-molecule is also known as a *mole*.

EXAMPLES

(i) The molecular weight of ammonia gas is 17; therefore, the *gram-molecule* or *gr. mol. wt.* of ammonia gas is 17 grams.

(ii) The molecular weight of nitrogen, N_2, is 28; therefore, the *gram-molecule* or *gr. mol. wt.* of nitrogen is 28 grams.

13. The *gram-molecular volume* of a gas is the volume occupied by its *gram-molecular* weight under normal conditions of temperature and pressure.

The *gram-molecular volume of every gas* under N.T.P. conditions is 22.4 liters. *This means that the gram-molecules of all gases fill the same volumes.* In accordance with Avogadro's Hypothesis this *means also that all gram-molecular volumes contain equal numbers of molecules.*

EXAMPLES

(i) The molecular weight of ammonia gas is 17; therefore, 17 grams of ammonia gas will occupy 22.4 liters at 0° and 760 mm., or 22.4 liters of NH_3 will weigh 17 grams.

(ii) The molecular weight of oxygen, O_2, is 32; therefore, 32 grams of oxygen will occupy 22.4 liters, or 22.4 liters of oxygen will weigh 32 grams.

(iii) The molecular weight of alcohol, C_2H_6O, is 46; therefore, 46 grams of alcohol vapor will occupy 22.4 liters at 0° and 760 mm., or 22.4 liters will weigh 46 grams.

(iv) Approximately 28.88 grams of air will occupy 22.4 liters at 0° and 760 mm.

MODEL EXAMPLE 19

(*a*) What will be the weight of 10 liters of hydrochloric acid gas under N.T.P. conditions?

(*b*) How many liters under N.T.P. conditions will 50 grams of oxygen occupy?

SOLUTION

(*a*) 22.4 liters of HCl will weigh 36.5 grams (Section 13), since the molecular weight of HCl is 36.5. Therefore, 1 liter of HCl will weigh $36.5/22.4 = 1.629$ grams, and 10 liters will weigh $10 \times 36.5/22.4 = 16.29$ grams.

(*b*) One gram-molecule of oxygen is 32 grams and occupies 22.4 liters. (Sections 12 and 13.) Therefore, one gram will occupy 22.4/32 liters, and 50 grams will take up the space of 50 x 22.4/32 = 35 liters.

MODEL EXAMPLE 20

How many liters of carbon dioxide under standard conditions of temperature and pressure will be set free by the action of hydrochloric acid on 250 grams of marble?

SOLUTION (i)

The weight of the CO_2 in grams must first be found as in Model Examples 7 and 8.

$$\begin{array}{lcccr} CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2 \\ 100 \qquad\qquad\qquad\qquad\qquad\quad 44 \\ 250 \qquad\qquad\qquad\qquad\qquad\quad x \end{array}$$

Wt. of CO_2: $100/44 = 250/x$; $x = 110$ grams.

To get the volume of CO_2: 44 grams of CO_2 will occupy 22.4 liters (Section 13); one gram will occupy 22.4/44 liters, and 110 grams will have the volume of 110 x 22.4/44 = 56 liters.

SOLUTION (ii)

Since the gram-molecule of every gas at 0° C. and 760 mm. occupies 22.4 liters (Section 13), every 44 grams (the gram-molecule) of CO_2 will occupy 22.4 liters, and the solution may be abbreviated by writing the equation as follows:

$$\begin{array}{lr} CaCO_3 + 2HCl = CaCl_2 + H_2O + & CO_2 \\ & (44) \\ 100 & 22.4 \\ 250 & x \end{array}$$

Volume of CO_2: $100/22.4 = 250/x$; $x = 56$ liters.

MODEL EXAMPLE 21

How many liters of ammonia gas under N.T.P. conditions can be obtained from 160.5 grams of sal ammoniac?

SOLUTION

$$\begin{array}{lcr} 2NH_4Cl + Ca(OH)_2 = CaCl_2 + H_2O + & & 2NH_3 \\ & & (2 \times 17) \\ 107 & & 2 \times 22.4 \\ 160.5 & & x \end{array}$$

Volume of NH_3: $107/44.8 = 160.5/x$; $x = 67.2$ liters.

MODEL EXAMPLE 22

How many grams of common salt will be required to make 100 liters of hydrochloric acid gas under S.T.P. conditions?

SOLUTION (i)

The *weight* of the HCl must first be obtained, because the weight of the NaCl, a solid, is desired. 22.4 liters of HCl will weigh 36.5 grams (the gram-molecule) of HCl (Section 13). Therefore, 100 liters of HCl will weigh $100 \times 36.5/22.4$ grams. (Model Example 19 (*a*).)

Note.—It is best not to approximate the value of the above fraction but to substitute the actual value in the equation in order to obtain more accurate results.

$$\begin{array}{lcr} 2NaCl + H_2SO_4 = Na_2SO_4 + & & 2HCl \\ 117 & & 73 \\ x & & 100 \times 36.5/22.4 \end{array}$$

Wt. of NaCl required: $117/73 = 22.4x/100 \times 36.5$;

$x = 261.16$ grams.

SOLUTION (ii)

Inasmuch as 2×22.4 may represent the volume of the HCl corresponding to the gram-molecular weight of 73 (Model Example 20 (ii)), the solution may be abbreviated as follows, because then the ratio between the molecular weight of the NaCl and its actual weight will be the same as the ratio between 2×22.4 and the volume (100 liters) of the HCl given.

$$\begin{array}{lcr} 2NaCl + H_2SO_4 = Na_2SO_4 + & & 2HCl \\ & & (73) \\ 117 & & 2 \times 22.4 \\ x & & 100 \end{array}$$

Weight of NaCl required: $117/x = 2 \times 22.4/100$;

$x = 261.16$ grams.

FORMULAS 7 AND 8

Wt. (in grams) = Molecular wt. x volume (in liters)/22.4, or, Grams = M.W. x liters/22.4. (Formula 7.)

Volume (in liters) = Wt. (in grams) x 22.4/Molecular wt., or, Liters = Grams x 22.4/M.W. (Formula 8.)

14. *Weights and Volumes in Kilograms and Cubic Meters.*

It is often convenient to express weights in kilograms and volumes in cubic meters. In such cases the gram-molecular-weights expressed in kilograms will occupy 22.4 cubic meters under N.T.P. conditions, because the same ratio exists between grams and kilograms (1:1000) as exists between liters and cubic meters (1:1000). (See Section 13.)

MODEL EXAMPLE 23

How many cu. meters of acetylene under N.T.P. conditions can be made from 10 kilograms of calcium carbide, CaC_2?

SOLUTION

$$\begin{array}{ccccccc} CaC_2 & + & 2H_2O & = & Ca(OH)_2 & + & C_2H_2 \\ & & & & & & (26) \\ 64 & & & & & & 22.4 \\ 10 & & & & & & x \end{array}$$

Vol. of gas: $64/22.4 = 10/x$; $x = 3.5$ cu. meters, or 3500 liters.

15. *Weights and Volumes in terms of English Weights and Measures.*

Since the ratio between kilograms and ounces (1000/28.35 = 35.27) is practically the same as the ratio between cu. meters and cu. ft. (1 cu. m. = 35.31 cu. ft.), the number 22.4 can be used in determining weights and volumes of substances in ounces and cu. ft. (Richards.)

MODEL EXAMPLE 24

How many cu. ft. of acetylene can be made from 25 lbs. of calcium carbide, CaC_2?

SOLUTION

$$\begin{array}{lcr}
\mathrm{CaC_2} + 2\mathrm{H_2O} & = \mathrm{Ca(OH)_2} + & \mathrm{C_2H_2}\\
 & & (26)\\
64 & & 22.4\\
25 \text{ x } 16\ (\text{oz.}) & & x
\end{array}$$

Vol. of gas: $64/22.4 = 400/x$; $x = 140$ cu. ft.

PROBLEMS

96. (*a*) What volume at 0° C. and 760 mm. will 120 grams of oxygen, O_2, occupy? (*b*) What will 1000 liters of ammonia gas at 0° C. and 760 mm. weigh?

97. How many grams would 22.4 liters of the following gases under N.T.P. conditions weigh: (*a*) chlorine, (*b*) nitrogen, (*c*) sulphur dioxide, (*d*) hydrobromic acid, (*e*) marsh gas?

98. How many liters under N.T.P. conditions will (*a*) 12 grams of nitrogen, (*b*) 15 grams of hydrogen, (*c*) 50 grams of chlorine, (*d*) 20 grams of carbon monoxide and (*e*) 100 grams of ethylene, C_2H_4, occupy?

99. What volume of oxygen measured under S.T.P. conditions can be obtained from 100 grams of potassium chlorate?

100. How many c.c. of nitrogen measured under N.T.P. conditions will be set free by heating 6.4 grams of ammonium nitrite, NH_4NO_2?

$$NH_4NO_2 = 2H_2O + N_2$$

101. How many liters of chlorine under standard conditions of temperature and pressure can be obtained from 78 grams of common salt?

102. How many grams of ammonium nitrate must be used to make 100 liters of "laughing gas" measured at 0° C. and 760 mm.?

103. What volume of carbon dioxide expressed in cu. meters at 0° C. and 760 mm. pressure would be set free by heating 1000 kilograms (a metric ton) of limestone?

$$CaCO_3 = CaO + CO_2$$

104. How many pounds of aluminum must be used to fill a balloon of 10,000 cu. ft. capacity with hydrogen if the gas is measured under N.T.P. conditions?

$$2Al + 6NaOH = 2Al(ONa)_3 + 3H_2$$

105. Calculate the volume of sulphur dioxide measured under standard conditions of temperature and pressure that can be obtained by the action of hot concentrated sulphuric acid on 38.1 grams of copper.

$$Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2$$

106. How much ferrous sulphide must be taken to furnish 750 c.c. of hydrogen sulphide measured under N.T.P. conditions?

$$FeS + 2HCl = FeCl_2 + H_2S$$

107. What will be the volumes in c.c. of the CO and CO_2 set free by the decomposition of 21 grams of oxalic acid, $C_2H_2O_4 \cdot 2H_2O$, if the gases are measured at 0° C. and 760 mm.?

$$C_2H_2O_4 \cdot 2H_2O = 3H_2O + CO_2 + CO$$

108. How many cu. ft. of CO and H, measured at 0° C. and 760 mm., will be formed by the action of steam on 1500 lbs. of coal?

$$C + H_2O = CO + H_2$$

109. How many cu. meters of nitrogen at 0° C. and 760 mm. will be needed to make 500 kilograms of calcium cyanamide, CaN_2Ca?

$$CaC_2 + N_2 = CN_2Ca + C$$

110. What would be the volumes of the gases at 0° C. and 760 mm. resulting from the burning of 10 grams of gunpowder?

$$2KNO_3 + 3C + S = K_2S + 3CO_2 + N_2$$

EXERCISE IX

EFFECT OF TEMPERATURE AND PRESSURE ON VOLUME

16. *Effect of Temperature when the Pressure remains constant.*

Between rather wide limits and under a constant pressure all gases expand when heated a certain fraction of what their volumes would be at 0° C. and contract in the same ratio when cooled.

EXAMPLE

If a liter of hydrogen at 0° C. is heated to 10° C., it will measure $1 + 10/273 = 283/273$ of a liter. Similarly, if the gas is cooled to $-10°$ C., the volume will become $1 - 10/273 = 263/273$ of a liter, when the pressure is kept uniform.

17. *Law of Dalton and Gay-Lussac.*

When the temperature of a gas is raised or lowered by one degree centigrade, its volume is increased or decreased by 1/273, or 0.00366 of the volume it occupies at 0° C., if, during the change in temperature, the pressure remains constant.

FORMULA 9

$V/V' = T/T'$, where V and V' are the volumes at different temperatures and T and T' are these temperatures expressed in C.°, but on the Absolute Scale. (See Section 2.)

PROOF OF FORMULA 9

Let V_0 be the volume of the gas at 0° C., V the volume at t° C. and V' the volume at t'° C.

Then, $V = V_0 + V_0t/273 = V_0(t + 273)/273$, (see example of this section).

$V' = V_0 + V_0t'/273 = V_0(t' + 273)/273$.

Dividing, $V/V' = t + 273/t' + 273$. By Section 2, $t + 273$ and $t' + 273$ expressed in centigrade degrees may be written T and T', to indicate the Absolute Scale, and the formula becomes $V/V' = T/T'$.

18. *Law of Charles.*

Instead of the above statement (Law of Dalton and Gay-Lussac), the law is often stated: The volume of a gas varies directly as its absolute temperature, the pressure being constant. This is known as the Law of Charles.

MODEL EXAMPLE 25

The volume of a gas at 15° C. is 27 c.c. What would be its volume at 0° C., if the pressure remains unchanged?

SOLUTION

By Formula 9, $V/V' = T/T'$. $T = 15 + 273 = 288$;

$T' = 0 + 273 = 273$. $V = 27$; $V' = x$.

$27/x = 288/273$; $x = 25.59$ c.c.

19. *Effect of Pressure when the Temperature is kept constant.*

LAW OF BOYLE OR MARIOTTE'S LAW

The volume of a gas varies inversely as its pressure, when the temperature remains constant.

FORMULA 10

$V/V' = P'/P$, where V and V' represent different volumes and P and P' the corresponding pressures.

(*a*) Pressure is measured by the height of the barometer column and is generally expressed in centimeters. It may be read in millimeters or in inches.

At sea level the atmospheric pressure supports a column of mercury 76 cm. or 30 in. high, when the temperature is zero and the weather is normal. This is standard pressure. As the pressure decreases or increases, the mercury falls or rises proportionately, and the above formula may be written $V/V' = h'/h$, where h and h' are the respective heights of the mercury column.

(*b*) Pressure is sometimes expressed in ***atmospheres***, in lbs. per sq. in. or in kg. per sq. cm. By this is meant the weight of the mercury column 1 sq. in. or 1 sq. cm. in cross section.

The average pressure of the atmosphere at sea level is 14.7 lbs. per sq. in., or 1033.3 g. per sq. cm. This is known as a pressure of 1 ***atmosphere***. As the pressure of the atmosphere is constantly changing, an atmosphere is often called in round numbers 15 lbs. per sq. in., or 1 kg. per sq. cm.

MODEL EXAMPLE 26

(*a*) The volume of a gas under 70 cm. pressure is 27 c.c. What will be its volume under a pressure of 76 cm., if the temperature is kept constant?

(*b*) 3.5 cu. ft. of acetylene gas are stored under a pressure of 10 atmospheres. What volume of gas would be furnished at a pressure of one atmosphere?

SOLUTIONS

(*a*) $V/V' = P'/P$, (Formula 10):

$27/x = 76/70$; $x = 24.86$ c.c. Ans.

(*b*) $V/V' = P'/P$, (Formula 10):

$3.5/y = 1/10$; $y = 35$ liters. Ans.

20. ***Effect of Temperature and Pressure combined.***

FORMULA 11

$V/V' = TP'/T'P$, where T and P are temperatures and pressures corresponding to V, and T' and P' are temperatures and pressures corresponding to V'.

PROOF OF FORMULA

Let V represent the original volume, V_2, the volume due to change of temperature only, and V', the volume due to change in both temperature and pressure.

Then, from the Law of Charles:

$$V/V_2 = T/T', \text{ that is, } V_2 = VT'/T;$$

from Boyle's Law,

$$V_2/V' = P'/P, \text{ that is, } V' = V_2P/P'.$$

But, $V_2 = VT'/T$. Substituting, $V' = VT'P/TP'$, which may be written:

$$V/V' = TP'/T'P.$$

Note.—In solving problems, errors may be avoided by first noting carefully the values corresponding to V, V', T, T', P and P', before substituting in the formula.

MODEL EXAMPLE 27

The volume of a gas at 15° C. and under 70 cm. pressure is 27 c.c. What will be the volume at 0° C. and under 76 cm. pressure?

SOLUTION

$V = 27$; $T = 273 + 15 = 288$; $P = 70$:

$V' = x$; $T' = 0 + 273 = 273$; $P' = 76$.

Substituting in the formula, $V/V' = TP'/T'P$,

$$27/x = 288 \text{ x } 76/273 \text{ x } 70; \quad x = 23.57 \text{ c.c.}$$

21. *Correction for effect of Aqueous Pressure on Volume in addition to the effect of Temperature and Pressure.*

The pressure of the water vapor in the volume of a moist gas opposes the atmospheric pressure, and the gas volume is enlarged. In making the correction for the pressure of the water vapor it is customary to bring water in contact with the gas to be measured in order to saturate it perfectly with moisture. The volume of the gas is then measured, and the tension of the aqueous vapor (obtained from a table) is deducted from the observed barometric pressure. The volume of the dry gas is then calculated by formula 11, that is, $V/V' = TP'/T'P$.

MODEL EXAMPLE 28

The volume of a gas contained in a tube over water, the level of the water inside and outside being the same, is 42 c.c.

at a temperature of 18° C. and under a pressure of 75.2 cm. What will be the volume of the dry gas under normal conditions of temperature and pressure?

SOLUTION

Let a be the pressure due to the water vapor. Then, the formula becomes $V/V' = TP'/T'(P - a)$. From the table in the appendix the pressure of water vapor at 18° C. is 1.53 cm. The net pressure on the gas is $75.2 - 1.53 = 73.67$ cm. The volume of the dry gas under normal conditions is:
$42/x = 291 \times 76/273(75.2 - 1.53)$;
$x = 38.17$ c.c. (Model Example 27.)

22. ***Volumes of Substances which do not exist as Vapors at 0° C. and 760 mm.***

Even if a substance does not exist in the gaseous state at 0° C. and 760 mm., the volume it occupies in a state of vapor can be determined.

For example, if steam existed at 0° C. and 760 mm., 18 grams of it would occupy 22.4 liters (Section 13). Its volume at any other temperature and pressure can readily be found from Formula 11. This is equally true of other substances.

MODEL EXAMPLE 29

What volume would 18 grams of steam at 100° C. and under pressure of 1000 mm. occupy?

SOLUTION

At 0° and 760 mm. 18 grams of steam would occupy 22.4 liters (Section 13). Then $V = 22.4$; $T = 273$; $P = 760$; $V' = x$; $T' = 100 + 273 = 373$; $P' = 1000$. (Formula 11 and Model Example 27.)

$$22.4/x = 273 \times 1000/373 \times 760 = 23.26 \text{ liters.}$$

PROBLEMS

111. A given weight of a gas measured 64 c.c. at 24° C. What would its volume become at 0° C., the pressure remaining constant?

112. A quantity of hydrogen at 30° C. and under a certain pressure measured 2.5 liters. What would be its volume at 10° C. under the same pressure?

113. A eudiometer tube contains 50 c.c. of hydrogen when the room is at a temperature of 22° C. The temperature falls to 15° C., and the height of the barometer remains the same. What is the change in volume?

114. A gas volume of 27.5 c.c. is changed from a room whose temperature is 15° C. to a room whose temperature is 25° C. What will be the increase in volume?

115. The volume of a gas at 18° C. is 21.2 c.c. What is the new temperature if the volume changes to 35.1 c.c. with no change in pressure?

116. A quantity of air measures 64 c.c. when the barometer stands at 74 cm. What would be its volume when the barometer reads 76 cm., the temperature remaining constant?

117. A quantity of hydrogen under a pressure of 80 cm. measures 2.5 liters. What will be its volume at the same temperature and under a pressure of 75 cm.?

118. A volume of gas at 18° C. and under 520 mm. pressure occupies 44 c.c. If the temperature is kept constant, under what pressure will the volume be doubled?

119. A volume of hydrogen measures 400 c.c. while the barometer stands at 750 mm. and the thermometer reads 20° C. Four hours later the temperature is the same but the volume is 410.2 c.c. What is the reading of the barometer?

120. Two cubic feet of laughing gas are stored under 20 atmospheres pressure. How much gas will be furnished at atmospheric pressure and at the same temperature?

121. 750 cu. ft. of oxygen under atmospheric pressure is pumped into a steel cylinder of 25 cu. ft. capacity, the temperature being kept constant. If the pressure of the atmosphere is 15 lbs. per sq. in., what is the pressure per sq. in. on the cylinder?

122. A gas in a cylinder of 50 liters capacity is compressed until it occupies a volume of 2.5 liters, with no change in temperature. How many times has the pressure been increased?

123. A gas tank can withstand a pressure of 40 atmospheres before breaking. If the tank holds 50 cu. ft. of gas under a pressure of one atmosphere, how much more gas can be forced into the tank, if the temperature is kept constant, before the tank will break?

124. If a hydrogen balloon of 5,000 liters capacity under standard pressure shrinks in a constant temperature to 4,800 liters, has the barometer risen or fallen, and how much?

125. A city gas tank on a certain day has a height of 30 feet. If, without any change in temperature and without any increase in the mass of the gas, the barometer drops from 758 to 748 mm., what will be the change in the height of the tank?

126. A quantity of air measures 64 c.c. at a temperature of 24° C. and under a pressure of 74 cm. What will be its volume at a temperature of 0° C. and under a pressure of 76 cm.?

127. A volume of hydrogen at a temperature of 30° C. and under a pressure of 80 cm. measures 2.5 liters. What will be its volume at 10° C. and 75 cm. of pressure?

128. A volume of gas at 18° C. and under 52 cm. of pressure measures 41 c.c. If the temperature is raised to the boiling point of water, what must be the pressure to double the volume?

129. The volume of a gas contained in a tube measures 86 c.c., the mercury standing at a height of 34 mm. in the tube. The barometric pressure is 742 mm.; the temperature is 23° C. What is the volume of the gas under standard conditions?

130. What volume of nitrous oxide (N_2O) measured at 10° C. and 750 mm. would be evolved by the decomposition of 10 grams of ammonium nitrate? *Hint.*—Obtain the volume of N_2O under standard conditions as per Model Example 20, and then find the volume at 10° C. and 750 mm. pressure as in Model Example 27.

131. (*a*) How much carbon dioxide by weight and by volume can be obtained from 53 grams of sodium carbonate? (*b*) What volume would the gas occupy at 20° C. and under a pressure of 75 cm. of mercury?

132. How much oxygen measured at 17° C. and 750 mm. pressure can be prepared from 473 c.c. of ozone measured at — 2° C. and 770 mm.? *Hint.*—Find the volume of the ozone at 17° C. and 750 mm. pressure by formula $V/V' = TP'/T'P$, and then multiply by 3/2, since $2O_3 = 3O_2$.

133. (*a*) What volume of hydrogen at 27° C. and 780 mm. can be obtained from 300 grams of sulphuric acid? (*b*) How much would it weigh?

134. What volume at 20° C. and under a pressure of two atmospheres will 100 liters of sulphur dioxide measured at 0° C. and under a pressure of one atmosphere occupy?

135. What volume of oxygen measured under 770 mm. pressure and at a temperature of 27° C. will be evolved when 108 grams of mercuric oxide are decomposed by heating?

136. The volume of a gas in a tube over water when measured at 20° C. and under a barometric pressure of 756 mm. is 25.2 c.c. What will be the volume of the dry gas under standard conditions of temperature and pressure? (See Model Example 28.)

137. What volume would one gram of steam occupy at a temperature of 100° C. and under normal pressure?

138. A quantity of hydrogen is set free by passing steam over highly heated iron and is collected over water. It occupies a volume of 48.2 c.c. at a temperature of 21° C. and under an observed barometric pressure of 756 mm. What would this quantity of hydrogen weigh under normal conditions of temperature and pressure?

139. 5 grams of ether, $C_4H_{10}O$, are vaporized in a space of 500 c.c. at a temperature of 35° C. What pressure will be exerted on the vessel?

140. 0.1041 gram of zinc was dissolved in dilute sulphuric acid and the resulting hydrogen was measured over water. The volume at 23° C. and 757 mm. pressure was 39.7 c.c. What is the atomic weight of zinc, if H = 1? *Hint.*—Obtain the weight of the hydrogen under normal conditions. Then x (atomic weight of zinc) : 2 (molecular weight of hydrogen) : : wt. of Zn : wt. of H.

141. How many lbs. of water would result from the condensation of 1,000 cu. ft. of steam under a pressure of 200 lbs. to the sq. in. and at a temperature of 195° C.?

142. A liter of dry oxygen weighs 1.43 grams under standard conditions. What must be the barometric pressure when the same weight of oxygen measured over water occupies 1.1 liters at a temperature of 15° C.?

143. 45 c.c. of air are measured over water at a temperature of 16° C. and under 758 mm. pressure. The oxygen is slowly burned out by means of phosphorus, and the volume over water at 18° C. and 754 mm. pressure measures 36.3 c.c. What was the percentage of oxygen in the air? *Hint.*—Obtain the volume of the air at 18° C. and 754 mm. The difference between that volume and 36.3 c.c. will be the volume of the oxygen. Then

$$\text{Volume of air} : \text{Volume of oxygen} :: 100 : x$$

144. Into a tank of 100 cu. ft. capacity 2,500 c.c. of air at — 25° C. are compressed. If the tank has a tested strength of 450 lbs. to the sq. in., below what temperature must the air be kept to keep the tank from bursting?

145. If 100 c.c. of ammonia gas are cooled to — 10° C. under 850 mm. pressure, what would the volume become at 20° C. and at 750 mm. pressure?

EXERCISE X

PROBLEMS INVOLVING TWO OR MORE REACTIONS

MODEL EXAMPLE 31

How many kilograms of calcium carbonate will furnish sufficient carbon dioxide to form 168 kilograms of sodium bicarbonate, using the principle of the Solvay Process?

SOLUTION

It is unnecessary to use the weights of the intermediate substances. One molecule of $CaCO_3$ will always yield one

100

molecule of $NaHCO_3$, and their weights will always be in the
84
proportion of 100 : 84.

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$$

Combining wts. .. 100 44
Wt. required x

$$NH_4OH + CO_2 = NH_4HCO_3$$

Combining wts. .. 44 79

$$NH_4HCO_3 + NaCl = NaHCO_3 + NH_4Cl$$

79 84
Actual weights .. 168
Wt. of $CaCO_3$: $100/84 = x/168$; $x = 200$ kilograms.

Model Example 32

(*a*) What weight of sulphur must be used for the sulphuric acid required to make 1,200 lbs. of superphosphate of lime?

(*b*) How many cu. ft. of SO_2 at 0° C. and 760 mm. will be formed?

Solution

$$(a)\ 2S + 2O_2 = 2SO_2$$

(64) (128)
x 2 x 22.4
y

$$2SO_2 + 2O + 2H_2O = 2H_2SO_4$$

Superphosphate of lime

$$Ca_3(PO_4)_2 + 2H_2SO_4 = 2CaSO_4 + CaH_4(PO_4)_2$$

506
1200

Two molecules of H_2SO_4 are needed to make one molecule of $CaH_4(PO_4)_2$ and two molecules of $CaSO_4$. Therefore, the weights of S and superphosphate of lime must have the ratio of 64 : 506, and 2 atoms of S must be used in the equation.

Weight of S required: $64/506 = x/1200$; $x = 151.78$ lbs.

(*b*) The superphosphate and the sulphur dioxide are in the ratio of 506 : 128 according to the above equation, and the cu. ft. of SO_2 at 0° C. and 760 mm. will be:

$44.8/y = 506/1200 \times 16$ (oz.);

$y = 1699.92$ cu. ft. (Model Example 24.)

PROBLEMS

146. If 50 grams of sulphuric acid act on copper, how many grams of acid sodium sulphite can be formed by the generated sulphur dioxide?

$$Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2$$
$$Na_2CO_3 + H_2O + 2SO_2 = 2HNaSO_3 + H_2O + CO_2$$

147. How much iron must be used to make the hydrogen necessary to reduce five grams of copper oxide to copper?

$$Fe + 2HCl = FeCl_2 + H_2$$
$$CuO + H_2 = Cu + H_2O$$

148. What weight of hydrochloric acid will generate the hydrogen sulphide required to change ten grams of copper sulphate to copper sulphide?

$$FeS + 2HCl = FeCl_2 + H_2S$$
$$CuSO_4 + H_2S = CuS + H_2SO_4$$

149. How much phosphorus will be changed to phosphorus pentoxide by the nitrous oxide set free from 10 grams of ammonium nitrate?

$$NH_4NO_3 = 2H_2O + N_2O$$
$$4P + 10N_2O = 2P_2O_5 + 10N_2$$

150. How much cupric oxide will be reduced by the carbon monoxide set free from 5 grams of oxalic acid?

$$C_2H_2O_4 \cdot 2H_2O = 3H_2O + CO_2 + CO$$
$$CuO + CO = Cu + CO_2$$

151. How many grams of potassium chlorate can be made from the chlorine obtained from 117 grams of common salt?

$$2NaCl + MnO_2 + 2H_2SO_4 = Na_2SO_4 + MnSO_4 + 2H_2O + Cl_2$$
$$6KOH + 3Cl_2 = 5KCl + KClO_3 + 3H_20$$

152. Ten grams of nitric acid acting on copper will form how much nitrogen peroxide?

$$3Cu + 8HNO_3 = 3Cu(NO_3)_2 + 4H_2O + 2NO$$
$$2NO + O_2 = 2NO_2$$

153. (*a*) To make one hundred grams of ammonium bicarbonate how much limestone will be needed to furnish the carbon dioxide?

(*b*) How many liters under N.T.P. conditions will the CO_2 occupy?

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$$
$$NH_4OH + CO_2 = NH_4HCO_3$$

154. How many pounds of sodium carbonate, making no allowance for loss, can be manufactured by the LeBlanc process from ten tons of common salt? (2,000 lbs. to the ton.) (*b*) How many cu. ft. at 0° C. and 760 mm. of CO_2 will be set free?

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$$
$$Na_2SO_4 + 2C = Na_2S + 2CO_2$$
$$Na_2S + CaCO_3 = Na_2CO_3 + CaS$$

155. What quantity of slaked lime can be made from two tons of limestone?

$$CaCO_3 = CaO + CO_2$$
$$CaO + H_2O = Ca(OH)_2$$

156. How much quicklime is needed to make 1,000 liters of acetylene under S.T.P. conditions?

$$CaO + 3C = CaC_2 + CO$$
$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2$$

157. How much sal ammoniac would be formed in manufacturing ten kilograms of sodium carbonate by the Solvay process? (*b*) How many cu. meters of CO_2 at 30° C. and 750 mm. pressure?

$$NaCl + NH_4OH + CO_2 = NaHCO_3 + NH_4Cl$$
$$2NaHCO_3 = Na_2CO_3 + H_2O + CO_2$$

158. How much calcium carbonate must be heated to get the carbon dioxide necessary to make 20 grams of hydrogen peroxide from barium peroxide?

$$CaCO_3 = CaO + CO_2$$
$$CO_2 + H_2O = H_2CO_3$$
$$BaO_2 + H_2CO_3 = BaCO_3 + H_2O_2$$

159. How much chloroform can be made from 10 grams of ethyl alcohol?

$$C_2H_6O + 4Cl_2 = C_2Cl_3HO + 5HCl$$
$$C_2Cl_3HO + KOH = CHCl_3 + KHCO_2$$

160. Assuming no by-products, how much ethyl alcohol will result from the fermentation of 100 grams of pure cane sugar?

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 \text{ (glucose)} + C_6H_{12}O_6 \text{ (fructose)}$$
$$C_6H_{12}O_6 + C_6H_{12}O_6 = 4C_2H_6O + 4CO_2$$

161. How much common salt must be electrolyzed to obtain 1,000 pounds of caustic soda?

$$2NaCl = 2Na + Cl_2$$
$$2Na + 2H_2O = 2NaOH + H_2$$

162. How many liters of oxygen under standard conditions of temperature and pressure will be needed for the complete combustion of ammonia gas from one hundred grams of sal ammoniac?

$$2NH_4Cl + Ca(OH)_2 = CaCl_2 + 2H_2O + 2NH_3$$
$$4NH_3 + 3O_2 = 6H_2O + 2N_2$$

163. How much fluor spar must be used to make 20.9 grams of silicon tetrafluoride?

$$CaF_2 + H_2SO_4 = CaSO_4 + 2HF$$
$$SiO_2 + 4HF = SiF_4 + 2H_2O$$

164. In ten hours 5 grams of the zinc of a Daniell's cell are dissolved. How much should the copper gain in weight?

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$
$$CuSO_4 + H_2 = Cu + H_2SO_4$$

165. If 1,000 lbs. of water enter a blast furnace in the heated air through the tuyeres, how much of the iron in the form of Fe_2O_3 will be reduced by the carbon monoxide resulting therefrom?

$$C + H_2O = H_2 + CO$$
$$Fe_2O_3 + 3CO = 2Fe + 3CO_2$$

EXERCISE XI

SPECIFIC GRAVITIES OF SOLIDS AND LIQUIDS

24. The ***specific gravity*** of a solid or liquid is the ratio between the weight 'of a given volume of the substance and the weight of an equal volume of distilled water at 4° C.

FORMULA 12

Sp. gr. $= W/V$, where W. is the wt. in grams and V. is the vol. of the substance in cubic centimeters.

PROOF OF FORMULA

In the metric system the unit of weight is the gram, which is the weight of 1 c.c. of distilled water at 4° C. (The error introduced by taking water at ordinary temperatures is for most practical purposes negligible.) For this reason, the number which represents the *volume* of water in c.c. may also represent the *weight* of the water in grams. Therefore, since the weight of an equal volume of water in grams is the same number as the volume of the substance which displaces the water, the sp. gr. of a substance = wt. in grams/vol. in c.c.

MODEL EXAMPLE 33

If 25 c.c. of sulphuric acid weigh 46 grams, what is the sp. gr. of the acid?

SOLUTION

Formula 12, sp. gr. $= W/V = 46/25 = 1.84$.

MODEL EXAMPLE 34

How much zinc will be dissolved by 200 c.c. of HCl, sp. gr. 1.18, and containing 35.6% by weight of the acid?

SOLUTION

Wt. of solution: $V \times$ sp. gr. $= 200 \times 1.18 = 236$ grams.
(Model Example 33.)

Wt. of HCl in solution: 236 x .356 = 84.02 grams.

$$\begin{array}{cccc} Zn & + \; 2HCl & = ZnCl_2 + H_2 \\ 65.5 & 73 & \\ x & 84.02 & \end{array}$$

Wt. of zinc: $65.5/73 = x/84.02$; $x = 75.39$ grams.

MODEL EXAMPLE 35

How many c.c. of nitric acid, density 1.1 and containing 17% by weight of the acid, will be required to neutralize a solution made by dissolving 50 grams of caustic soda in water?

SOLUTION

$$\begin{array}{cccc} NaOH & + \; HNO_3 & = NaNO_3 + H_2O \\ 40 & 63 & \\ 50 & x & \end{array}$$

Wt. of HNO_3 required: $63/40 = x/50$; $x = 78.75$ grams.

Since the acid is 17% or .17 of the solution, the weight of the solution is $78.75/.17 = 463.24$ grams. $V = W/\text{sp. gr.}$ (Formula 12), and the volume of the solution is $463.24/1.1 = 421.1$ c.c.

PROBLEMS

166. If 35 c.c. of a solution weigh 38.5 grams, what is its specific gravity?

167. If the specific gravity of a substance is 7.8, what volume will 546 grams of it occupy?

168. A cube of marble, 10 cm. long, weighs 2,500 grams. What is the specific gravity of the marble?

169. A lump of coal weighing 80 grams displaces 51.2 c.c. of water. What is the specific gravity of the coal? *Hint.*—Volume of coal must be 51.2 c.c.

170. (*a*) A liquid with a specific gravity of 0.9 is mixed with (*b*) a liquid of specific gravity 1.2. The specific gravity of the solution is 1.05. How many c.c. of each in a liter? *Hint.*—Let x be the volume of one: then $1,000 - x$ will be the volume of the other.

171. 500 c.c. of sulphuric acid, sp. gr. 1.84, is added to two

liters of water. What is the specific gravity of the solution? (No allowance for diminution of volume.)

172. One liter of sodium carbonate solution contains 9.43% of Na_2CO_3 and has a specific gravity of 1.1. How many liters of carbon dioxide at 0° C. and under 760 mm. pressure could be set free from the solution by the action of an acid? *Hint.*—First determine the weight of Na_2CO_3 in one liter.

173. If 10 c.c. of a liquid whose density is 1.20 be added to 40 c.c. of a liquid whose density is 1.25, and the result diluted with twice its volume of water, what is the density of the mixture, the temperature being 4° C.?

174. Water exerts an upward pressure that is equivalent to the weight of the liquid displaced. If a piece of an unknown mineral weighs 111 grams in air, when suspended from a spring balance, and weighs but 99 grams when submerged in water, what is the specific gravity of the mineral?

175. A piece of rock displaces 41 c.c. of a liquid whose density is 1.3. It loses one-third of its weight in this liquid. What is its specific gravity?

176. What weight of barium acetate will result from the action of 2,000 c.c. of acetic acid, sp. gr. 1.04 and containing 29% by weight of the acid, on Witherite?

$$BaCO_3 + 2HC_2H_3O_2 = Ba(C_2H_3O_2)_2 + H_2O + CO_2$$

177. How much metallic bismuth will be dissolved by 500 c.c. of nitric acid, sp. gr. 1.2 and containing 32.2% by weight of the acid?

$$Bi + 4HNO_3 = Bi(NO_3)_3 + 2H_2O + NO$$

178. How many c.c. of a solution of sodium carbonate, sp. gr. 1.1 and containing 25.4% of Na_2CO_3, will be required to make 100 grams of sodium sulphate?

$$Na_2CO_3 + H_2SO_4 = Na_2SO_4 + H_2O + CO_2$$

179. How many grams of stannous chloride will result from the action of 350 c.c. of hydrochloric acid (density 1.14 and 27.7% by weight of the acid), on tin?

$$Sn + 2HCl = SnCl_2 + H_2$$

180. What per cent of NH_3 must be in a solution of 100 c.c. of ammonia which has a sp. gr. of .90 and is neutralized by a solution containing 95 grams of oxalic acid, $C_2H_2O_4 \cdot 2H_2O$?

$$C_2H_2O_4 \cdot 2H_2O + 2NH_3 = (NH_4)_2C_2O_4 + 2H_2O$$

181. (*a*) How many grams of hydrochloric acid must be dissolved per liter to make a 20% solution with a sp. gr. of 1.1.? (*b*) What volume at 0° C. and 760 mm. would the gas occupy?

182. How much available chlorine (in liters at 0° C. and 760 mm.) would there be in 10 liters of bleaching powder ($CaOCl_2$) solution, sp. gr. 1.1 and containing 5.6% of chlorine?

183. How many c.c. of sulphuric acid, sp. gr. 1.84 and 95.6% of acid, will make 139 grams of green vitriol, $FeSO_4 \cdot 7H_2O$?

$$Fe + H_2SO_4 + 7H_2O = FeSO_4 \cdot 7H_2O + H_2$$

184. How many liters of CO_2 under standard conditions of temperature and pressure will make 690 c.c. of a 30% solution of potassium carbonate, sp. gr. 1.3, from caustic potash?

$$2KOH + CO_2 = K_2CO_3 + H_2O$$

185. How many c.c. of hydrochloric acid, sp. gr. 1.15 and 29.6% of acid, and how many c.c. of nitric acid, sp. gr. 1.13 and 47.5% of acid, will be required to make 32.5 grams of ferric chloride?

$$Fe + 3HCl + HNO_3 = FeCl_3 + 2H_2O + NO$$

EXERCISE XII

CALCULATION OF FORMULAS

25. *When the Vapor Density of the Compound is not given.* When the percentage composition of a substance is given, the ratio of the atoms can be determined, and the *simplest* but not necessarily the actual formula can be calculated.

Model Example 36

(*a*) A compound analyzes: Fe, 70%; O, 30%. What is its simplest formula? At. wts.: Fe, 56; O, 16.

(*b*) A substance analyzes: Fe, 20%; S, 11.5%; O, 23%; H_2O, 45.3%. What is its simplest formula? At. wts.: Fe, 56; S, 32; O, 16; H, 1.

Solutions

	Fe	O
(*a*) Ratio of weights	56)70	16)30
Ratio of atoms	1.25)1.25	1.875
	1	1.5
Ratio in whole numbers	2	3

The simplest formula is Fe_2O_3.

	Fe	S	O	H_2O
(*b*) Ratio of weights	20.	11.5	23	45.3
Ratio of atoms	56)20	32)11.5	16)23	18)45.3
	.36).36	.36	1.44	2.52
Ratio in whole numbers	1	1	4	7

The simplest formula is $FeSO_4 \cdot 7H_2O$.

Model Example 37

A substance contains the following: CaO, 30.42%; MgO, 21.71%; CO_2, 47.75%. What is its simplest formula? At. wts.: Ca, 40; Mg, 24.5; O, 16; C, 12.

Solution

	CaO	MgO	CO_2
Ratio of weights	30.42	21.71	47.75
Ratio of groups of atoms	56)30.42	40.5)21.71	44)47.75
	.536).543	.536	1.085
Ratio in whole numbers	1	1	2

The simplest formula is CaO, MgO, $2CO_2$ or $CaCO_3$, $MgCO_3$.

26. ***When the Vapor Density of the Compound is given.***

When the vapor density as well as the percentage composition of a substance is given, the *exact* formula can be determined because the molecular weight is known. (M.W. = 2V.D. from Formula 4.)

MODEL EXAMPLE 38

The vapor density of ethyl alcohol is 23. It contains by weight: carbon, 52.18%; hydrogen, 13.04%; oxygen, 34.78%. What is its formula? At. wts. C, 12; O, 16; H, 1.

SOLUTION

The molecular weight is $2 \times 23 = 46$ (Formula 4.)

Parts of carbon in the molecule : $46 \times .5218 \doteq 24.00$

Parts of hydrogen in the molecule : $46 \times .1304 \doteq 5.99$

Parts of oxygen in the molecule : $46 \times .3478 = 15.99$

Atoms of carbon in the molecule : $24.00/12 = 2$

Atoms of hydrogen in the molecule : $5.99/1 = 6$

Atoms of oxygen in the molecule : $15.99/16 = 1$

The formula of the gas is C_2H_6O.

PROBLEMS

186. An ore has the following percentage composition:

Al	45%
O	40%
H_2O	15%
	100%

What is its simplest formula?

187. Every hundred parts of a compound contain the following by weight:

Na	32.86 parts.
Al	12.84 parts.
F	54.29 parts.

What is its simplest formula?

188. Determine the simplest formula for an ore that analyzes: uranium, 84.82%; oxygen, 15.17%.

189. What is the formula for a compound that has in it: CaO, 56%; CO_2, 44%?

190. The composition of an ore is Cu, 79.45%; S, 20.32%. What is the simplest formula? What is the name of the ore?

191. Brucite has approximately the following composition: MgO, 69%; H_2O, 31%. What is the simplest formula?

192. A specimen of Willemite is found to contain the following: ZnO, 72.9%; SiO_2, 26.9%. What is its simplest formula?

193. A specimen of limonite analyzes approximately: Fe_2O_3, 85.5%; H_2O, 14.4%. What is its simplest formula?

194. A specimen of topaz has the following composition: Si, 15.15%; Al, 29.53%; O, 34.70%; F, 20.60%. What is the simplest formula?

195. A liter of a gas under standard conditions of temperature and pressure weighs 1.259 grams. It contains: carbon, 85.71%; hydrogen, 14.29%. What is its formula?

196. The vapor density of a gas is 13. It analyzes: carbon, 92.31%; hydrogen, 7.69%. What is its formula?

197. The density of a vapor is 49.5. Its percentage composition is: carbon, 24.24%; hydrogen, 4.04%; chlorine, 71.72%. What is its formula?

198. The vapor density of chloral is 73.75. It analyzes as follows:

Carbon	16.28%
Chlorine	72.20%
Oxygen	10.85%
Hydrogen	.68%
	100.01%

What is its formula?

199. Phosgene gas or carbonyl chloride is 49.5 times as heavy as hydrogen. Its composition is as follows:

Carbon	12.12%
Oxygen	16.16%
Chlorine	71.72%
	100.00%

What is its formula?

200. Pentane has a specific gravity of 36 with reference to hydrogen as 1. Its composition is:

Carbon	83.33%
Hydrogen	16.67%
	100.00%

What is its formula?

201. 100 c.c. of a gas weigh 0.115 gram when one c.c. of hydrogen weighs 0.000085 gram. The gas is composed of

Hydrogen	3.70%
Nitrogen	51.85%
Carbon	44.44%
	99.99%

What compound is it?

202. A gas is 2.43 times as heavy as oxygen. Its composition is:

Carbon	92.31%
Hydrogen	7.69%
	100.00%

What is its formula?

203. A gas is 6.16 times as heavy as carbon dioxide. Its composition is:

Mercury	73.80%
Chlorine	26.20%
	100.00%

What is its formula?

204. 100 liters of a gas balance 121.43 liters of nitrogen. The gas analyzes:

Sulphur	94.12%
Hydrogen	5.88%
	100.00%

What is its formula?

205. (*a*) A gas contains 7 parts by weight of nitrogen and 8 parts by weight of oxygen. What is its simplest formula? (*b*) If its vapor density is 30, what is its actual formula?

EXERCISE XIII

DETERMINATION OF ATOMS IN MOLECULES

MODEL EXAMPLE 39

Two volumes of hydrogen and one volume of oxygen will combine to form two volumes of water vapor. How many atoms are there in the molecules of oxygen and hydrogen, and how should the molecular formulas for hydrogen and oxygen be written?

SOLUTION

$$2 \text{ vols. H} + 1 \text{ vol. O} = 2 \text{ vols. } H_2O$$

Let $x =$ the number of molecules in *one* volume. By Avogadro's Hypothesis, equal volumes of all gases under the same conditions of temperature and pressure contain the same number of molecules. Therefore, the ratio of the molecules becomes $2x$, x and $2x$.

Since there are two atoms of hydrogen and one atom of oxygen in one molecule of water vapor (H_2O), there will be $4x$ atoms of hydrogen and $2x$ atoms of oxygen in the two volumes of water vapor. These atoms came from the $2x$ molecules of hydrogen and the x molecules of oxygen; therefore, there must have been 2 atoms each in the molecules of hydrogen and oxygen, and the molecular formulas should be written H_2 and O_2.

The solution may be stated more graphically as follows:

$$\begin{array}{lccc} & 2 \text{ vols. H} + & 1 \text{ vol. O} = & 2 \text{ vols. } H_2O \\ \text{Ratio of molecules:} & 2x & x & (2x) \\ & & & \left\{\begin{array}{l} 4x \text{ atoms of H.} \\ 2x \text{ atoms of O.} \end{array}\right. \end{array}$$

Atoms of H in one molecule: $4x/2x = 2$.
Atoms of O in one molecule: $2x/x = 2$.
Molecular formulas are H_2 and O_2.

MODEL EXAMPLE 40

The vapor density of bromine vapor is 79.9. What is its molecular formula? At. wt.: 80.

SOLUTION

Molecular wt.: $2 \times 79.9 = 159.8$. (Formula 4.)
Atoms in molecule: $159.8/80 = 2$. Formula is Br_2.

MODEL EXAMPLE 41

Chlorine is 2.49 as heavy as air. What is its molecular formula? At. wt., 35.5.

SOLUTION

M.W. of Cl $= 2.49 \times 28.88$ (Formula 5).
$= 71.9$.
Atoms in molecule $= 71.9/35.5 = 2$.
Molecular formula is Cl_2.

PROBLEMS

206. One volume of hydrogen and one volume of chlorine unite to form two volumes of hydrochloric acid gas. (*a*) How many atoms in a molecule of chlorine? (*b*) Write its molecular formula.

207. Three volumes of hydrogen and one volume of nitrogen will result from the decomposition of two volumes of ammonia gas. Show that the molecular formula of nitrogen is N_2.

208. Two liters of nitrous oxide, N_2O, yield two liters of nitrogen and one liter of oxygen. Use this to show that there are two atoms in a molecule of oxygen.

209. (*a*) The vapor density of argon is 19.96. Its atomic weight is 39.9. What is its molecular formula? (*b*) Zinc vapor is 32.8 as heavy as hydrogen. What is its molecular formula?

210. (*a*) The vapor density of arsenic vapor is 150. How many atoms to the molecule does this indicate? (*b*) At about 1700° C. arsenic appears to have 2 atoms to the molecule. What must be its vapor density at this temperature?

211. 100 c.c. of mercuric chloride vapor ($HgCl_2$) may be decomposed into 100 c.c. of mercury vapor and 100 c.c. of chlorine gas. Determine the molecular formula for mercury.

212. (*a*) Krypton is 2.82 times as heavy as air. If its atomic weight is 82, how many atoms in its molecule? (*b*) Helium is .137 times as heavy as air. What is its molecular formula?

213. Two liters of ozone may be decomposed into three liters of oxygen. What must be the molecular formula for ozone, assuming the molecular formula for oxygen to be O_2?

214. (*a*) Sulphur at about 900° C. has a vapor density of 32. How many atoms in its molecule at this temperature? (*b*) At low temperatures sulphur has a vapor density of 128. What is its molecular formula?

215. When two volumes of phosphine are decomposed, three volumes of hydrogen and one-half volume of phosphorus vapor result. What is the molecular formula for phosphorus?

EXERCISE XIV

DETERMINATION OF ATOMIC WEIGHTS

27. *Method of Specific Heats.*

This method is based on the Law of Dulong and Petit which is as follows: *The specific heats of solids are inversely proportional to their atomic weights.*

This means that the product of the specific heat of a solid by its atomic weight is a constant. This constant is approximately 6.4 and is called the Atomic Heat of the element.

Therefore, since sp. heat x atomic weight = 6.4, atomic weight = 6.4/sp. heat.

FORMULA 13

$$\text{At. wt.} = 6.4/\text{sp. heat}$$

MODEL EXAMPLE 42

The specific heat of a metal is .108. What is its approximate atomic wt.?

SOLUTION

$$\text{At. wt.} = 6.4/.108 = 59 \quad \text{(Formula 13)}.$$

Note.—This method yields only approximate results, and it is generally used to check other methods.

28. *Method of Equivalents and Specific Heats.*

The equivalent of an element is that weight which will enter into combination with or replace one part by weight of hydrogen.

For example, 1 part by wt. of H will combine with 35.5 parts of Cl; 35.5 is the equivalent of chlorine.

The equivalent of an element always bears some numerical relation to its atomic weight. This relation in the case of solids may often be ascertained by making use of the specific heat of the element.

For example, suppose by experiment the equivalent of zinc is found to be 32.8. Since its sp. heat is .094, its atomic weight would be approximately $6.4/.094 = 68$. This indicates that the atomic weight is $2 \times 32.8 = 65.6$, and that the valence of zinc is 2.

MODEL EXAMPLE 43

.115 gram of sodium set free 56.2 c.c. of hydrogen under N.T.P. conditions from hydrochloric acid gas. What is the equivalent of sodium, and what is its atomic weight? The sp. heat of sodium is .293.

SOLUTION

The wt. of H set free is $.0562 \times 2/22.4 = .005$ gram. (Formula 7.)

The equivalence of the sodium is $Na/H = .115/.005 = 23$.

At. wt. $= 6.4/.293 = 22$. (Model Example 42.) Therefore, the atomic weight of sodium may be taken as 23.

29. *Method of Reduction, Precipitation, etc.*

These methods can be shown best by examples.

MODEL EXAMPLE 44

Five grams of copper oxide when heated in a current of hydrogen lost 1.006 grams. Calculate the atomic weight of copper, assuming the atomic weight of oxygen to be 16.

SOLUTION

	CuO	$+ H_2 =$	Cu	$+ H_2O$
Combining wts.	$x + 16$		x	
Actual wts.	5		3.994	

Wt. of copper resulting: $5.000 - 1.006$ (wt. of O) $= 3.994$ grams.

At. wt. of Cu: $x + 16/x = 5/3.994$; $x = 63.5$.

This result may be checked by using the sp. heat of copper which is .094. (Model Example 42.) At. wt. $= 6.4/.094 = 68$. This may be used to confirm the above result.

MODEL EXAMPLE 45

Marignac found that 100 parts of pure silver dissolved in nitric acid and precipitated by bromide of potassium yielded 174.065 parts of bromide of silver. He used 108 as the atomic weight of silver. What would be the atomic weight of bromine according to this method?

SOLUTION

$$\begin{array}{l} 3Ag + 4HNO_3 = 3AgNO_3 + NO + 2H_2O \\ 3 \times 108 \\ 100 \end{array}$$

$$\begin{array}{ccc} 3AgNO_3 + 3KBr = & 3AgBr & + 3KNO_3 \\ & 3(108 + x) & \\ & 174.065 & \end{array}$$

This becomes merely a problem involving the Law of Definite Proportions, and the atomic wt. of Br: $324/324 + 3x = 100/174.065$; $x = 79.9$.

MODEL EXAMPLE 46.

Pure calcium carbonate was treated with pure con. H_2SO_4, the resulting calcium sulphate was washed with absolute alcohol, dried at 100° and weighed. 100 parts of $CaCO_3$ yielded 135.957 parts of $CaSO_4$. If $C = 12$, $O = 16$ and $S = 32$, what is the atomic weight of calcium?

SOLUTION

$$\begin{array}{cccc} CaCO_3 + H_2SO_4 = & CaSO_4 & + H_2O + CO_2 \\ (x + 12 + 48) & (x + 32 + 64) & \\ x + 60 & x + 96 & \\ 100 & 135.957 & \end{array}$$

At wt. of calcium: $x + 60/x + 96 = 100/135.957$; $x = 40.1$.

30. *Method of Vapor Densities and Percentage Compositions.* As many compounds as possible containing the element whose atomic weight is required are converted into vapor, and their vapor densities are determined. From the vapor densities the molecular weights are calculated. By analysis, the weights of the element in question in the molecular weights of the compounds can be determined. Since there is never less than one atom of an element in the compounds of that element, the smallest weight of the element present in all of the compounds may be taken as the atomic weight of the element.

MODEL EXAMPLE 47.

Compound	Vapor Density	Composition
Water	9	O, 88.88%
Carbon monoxide	14	O, 57.14%
Carbon dioxide	22	O, 72.73%
Nitric oxide	15	O, 53.33%
Nitrous oxide	22	O, 72.73%
Oxygen	16	At least two atoms to the molecule

SOLUTION

Molecular wt. of $H_2O = 2 \times 9 = 18$;
wt. of O in molecule $= 18 \times .8888 = 16$
Molecular wt. of $CO = 2 \times 14 = 28$;
wt. of O in molecule $= 28 \times .5714 = 16$
Molecular wt. of $CO_2 = 2 \times 22 = 44$;
wt. of O in molecule $= 44 \times .7273 = 32$
Molecular wt. of $NO = 2 \times 15 = 30$;
wt. of O in molecule $= 30 \times .5333 = 16$
Molecular wt. of $NO_2 = 2 \times 22 = 44$;
wt. of O in molecule $= 44 \times .7273 = 32$

Since the smallest weight of oxygen in any molecule is 16, the atomic weight of oxygen may be taken as 16.

216. Find the approximate atomic weights of the following:

(*a*) Cæsium ....sp. heat .048
(*b*) Platinum ....sp. heat .032
(*c*) Nickel ....sp. heat .108
(*d*) Tin ....sp. heat .055
(*e*) Iron ....sp. heat .116

217. (*a*) The chloride of a metal contains 79.77% of chlorine. If the equivalent of chlorine is 35.5, what is the equivalent of the metal?

(*b*) If the specific heat of the metal is .22, what is its atomic weight?

(*c*) What is the valence of the metal?

218. (*a*) .1025 gram of zinc is dissolved in dilute sulphuric acid, and the hydrogen set free measures 35.3 c.c. under standard conditions. What is the equivalent of zinc? (*b*) The specific heat of zinc is .094. What is its atomic weight? (*c*) What is the valence of zinc?

219. Rose found that 100 parts of chloride of strontium yielded by precipitation 181.25 parts of chloride of silver. If he assumed 108 as the atomic weight of silver and 35.5 as the atomic weight of chlorine, what value did he obtain for the atomic weight of strontium?

220. 8.3 grams of nickel oxide when heated in a current of hydrogen lose 1.78 grams in weight. What is the atomic weight of nickel, when O = 16?

221.

Compound	Vapor Density	Composition
Nitric oxide	15	N, 63.63%
Nitrous oxide	22	N, 46.67%
Ammonia gas	8.5	N, 82.35%
Nitrogen	14	At least 2 atoms to molecule

From this data determine the atomic wt. of nitrogen.

222.

Compound	Vapor Density	Composition
Hydrochloric acid	18.25	Cl, 97.36%
Carbon tetrachloride	77	Cl, 92.21%
Chloroform	58.75	Cl, 89.12%
Methyl chloride	25.25	Cl, 70.30%

Determine the atomic weight of chlorine.

223.

Compound	Vapor Density	Composition
Carbon dioxide	22	C, 27.27%
Ethylene	14	C, 85.71%
Carbon tetrachloride	77	C, 7.79%
Ethyl alcohol	23	C, 52.17%
Propane	22	C, 81.82%

Determine the atomic weight of carbon.

224. Berzelius analyzed chloridiate of potassium, $2KCl \cdot IrCl_4$, and found that 100 parts of it lost 29 parts of chlorine. The KCl was not decomposed. If $K = 39.2$ and $Cl = 35.5$, what is the atomic weight of iridium?

225. From 5.33 grams of NH_4Cl were precipitated 14.33 grams of AgCl. If the atomic weights are: Cl, 35.3; Ag, 108; H, 1; find the atomic weight of nitrogen.

226. Chloride of silver contains 75.26% of silver and 24.74% of chlorine. Calculate the atomic weight of silver when Cl is 35.5.

227. From 1.50903 grams of tantalum pentabromide .57570 gram of tantalum pentoxide were obtained. (Jour. Am. Ch. Soc., Sept. 11th, '13.) If $Br = 79.92$ and $O = 16$, what is the atomic weight of tantalum?

$$2TaBr_5 + 10H_2O = Ta_2O_5 \cdot 5H_2O + 10HBr;$$

$$Ta_2O_5 \cdot 5H_2O = Ta_2O_5 + 5H_2O.$$

228. From 10.0811 grams of mercuric bromide were obtained 10.5044 grams of silver bromide. Taking $Ag = 107.9$ and $Br = 79.9$, calculate the atomic weight of mercury.

229. From 1.2912 grams of calcium carbonate dissolved in pure con. sulphuric acid 1.7561 grams of calcium sulphate were obtained. Calculate the atomic weight of calcium, when $O = 16$, $S = 32$ and $C = 12$.

230. In 100 parts of stannic chloride there are 54.5 parts of chlorine and 45.4 parts of tin. If the atomic weight of chlorine is 35.5, and the specific heat of tin is .054, (*a*) calculate the atomic weight of tin; (*b*) what is the valence of the tin?

EXERCISE XV

ELECTROLYSIS

31. *Faraday's Laws.*

(i) The amounts of substances separated at the electrodes during electrolysis in a given time are proportional to the strength of the current passing through the electrolyte.

For example, if one gram of a certain substance is deposited in a given time by one unit of current, a current of five units would deposit 5 grams in the same time.

(ii) The amounts of the different products separated by a given current of electricity bear the same relation to each other as their " *equivalents*."

By " *equivalent* " is meant that amount of an element which will combine with or replace one part by weight of hydrogen.

FORMULA 14

$$\text{Equivalent} = \text{atomic weight}/\text{valence}$$

MODEL EXAMPLE 48

If a certain current is passed through the following solutions arranged in series, what will be the ratios of the different substances deposited: silver nitrate, copper sulphate, auric chloride and tin tetrachloride?

SOLUTION

Formulas:	$AgNO_3$	$CuSO_4$
	(108 + 14 + 48)	(63.5 + 32 + 64)
Positive elements or *anions*	Ag	Cu
Ratios of *anions* set free	108/1	63.5/2 = 31.75
Negative elements or *cations*	NO_3	SO_4
Ratios of *cations* set free	62/1 = 62	96/2 = 48
Formulas:	$AuCl_3$	$SnCl_4$
	(197 + 106.5)	(118.5 + 142)
Positive elements or *anions*	Au	Sn
Ratios of *anions* set free	197/3 = 65.67	118.5/4 = 29.63
Negative elements or *cations*	Cl	Cl
Ratios of *cations* set free	106.5/3 = 35.5	142/4 = 35.5

32. It has been determined that *96540* coulombs of electricity will deposit *one gram-equivalent* of any substance.

(*a*) A *gram-equivalent* is the number of grams which will combine with or replace one gram of hydrogen.

FORMULA 15

Gram-equivalent = atomic weight / valence (expressed in grams). The quotient will represent the number of grams of the substance deposited by 96,540 coulombs.

(*b*) A *coulomb* is a unit quantity of electricity.

(*c*) When electricity is being furnished at the rate of *one coulomb per second*, it is called an *ampere.*

(*d*) In terms of their chemical effects *coulomb* and *ampere* may be defined as follows: The quantity of electricity which deposits .001118 gram of silver is *one* coulomb, and the current which deposits silver at the rate of *.001118 gram per second* is *one ampere.*

33. Electrochemical Equivalent is the amount of a substance deposited by one coulomb and is equal to the gram-equivalent divided by 96,540.

FORMULA 16

Electrochemical Equivalent = Gram equivalent/96,540.

MODEL EXAMPLE 49

The atomic weight of oxygen is 16, and its valence is 2. What is its electrochemical equivalent?

SOLUTION

8 grams is its gram-equivalent (Section 32 (*a*)). Therefore, its electrochemical equivalent is 8/96,540 = .0000828 gram (Formula 16).

MODEL EXAMPLE 50

The atomic weight of copper is 63.5 and its valence is 2. What is its electrochemical equivalent?

SOLUTION

31.75 is its gram-equivalent. Therefore, its electrochemical equivalent is 31.75/96,540 = .000328 gram.

PROBLEMS

231. (*a*) If the atomic weight of gold is 197 and its valence is 3, what is its electrochemical equivalent? (*b*) How much gold would be set free in twenty-four hours by a current of 10 amperes?

232. How many coulombs of electricity will be required to deposit 45 grams of tin from a solution in which the tin exists in a bivalent form?

233. (*a*) If a current of one ampere sets free .0000104 gram of hydrogen in one second, how much nitrogen would a current of the same strength set free in the same time? (*b*) If the electrochemical equivalent of silver is .001118, what is the electrochemical equivalent of nickel?

234. If the electrochemical equivalent of copper is .000329, how much electrolytic copper would be deposited on the cathode of a bath of copper sulphate containing an anode of impure copper by a current of 30 amperes in 24 hours?

235. The copper plate (cathode) of a Daniell's cell gains 6.99 grams in weight in a given time. How much should the zinc lose in the same time?

236. Calculate the weights of (*a*) copper, (*b*) zinc and (*c*) gold which can be deposited from their respective solutions by 21,600 coulombs.

237. A current of a certain strength was passed through three solutions, viz., water acidulated with sulphuric acid, copper sulphate and gold chloride ($AuCl_3$). When 5 grams of copper are deposited, what weights of (*a*) hydrogen, (*b*) oxygen and (*c*) gold will have been set free?

238. How many grams of (*a*) sodium, (*b*) magnesium and (*c*) iron (ferric) would be deposited by a current of 2.2 amperes in 5 hours?

239. What weight of silver will have been deposited from a nitrate of silver solution when the same current sets free 310.2 c.c. of hydrogen measured over water at 16° C. and 758 mm.?

240. How many amperes of electricity will be required to set free 500 grams of copper from a solution of copper sulphate in 10 hours?

EXERCISE XVI

STANDARD SOLUTIONS AND VOLUMETRIC ANALYSIS

34. *Normal Solutions.*

A normal solution is a solution one liter of which contains one gram (more exactly 1.008 grams) of hydrogen or the hydrogen equivalent of the active element expressed in grams.

(*a*) Examples of normal solutions.

(i) Univalent substances.

HCl; M.W. = 36.5. One liter contains
36.5 g. of HCl or 1 g. of H.

$AgNO_3$; M.W. = 170. One liter contains
170 g. of $AgNO_3$ or 108 g. of Ag.

$NaOH$; M.W. = 40. One liter contains
40 g. of $NaOH$, or 17 g. of OH.

(ii) Bivalent substances.

H_2SO_4; M.W. = 98. One liter contains
98/2 = 49 grams of H_2SO_4 or 1 g. of H.

Na_2CO_3; M.W. = 106. One liter contains
106/2 = 53 grams of Na_2CO_3 or 23 g. of Na.

(iii) Trivalent substances.

$HNa_2PO_4 \cdot 12H_2O = 358$. One liter contains 358/3 = 119.3 grams of the salt, for $PO_4 = 3H$.

(*b*) Seminormal, quintinormal, decinormal and centinormal solutions are frequently used, and they are known as N/2, N/5, N/10 and N/100 solutions.

MODEL EXAMPLE 51

Show that a definite volume of a normal solution of an acid will neutralize an equal volume of a normal solution of an alkali, and vice versa, or 1 c.c. of a normal acid = 1 c.c. of a normal alkali.

SOLUTION

1 c.c. of a normal solution of HCl will contain 36.5/1000 = .0365 gram; 1 c.c. of a normal solution of KOH will contain 56/1000 = .056 gram (Section 34).

These substances combine according to the following equation and weights:

	KOH	+ HCl	= KCl + H_2O
Combining weights	56	36.5	
Weight in 1 c.c.	.056	.0365	

From this it is evident that the HCl and KOH have the same ratio in the solution as that which exists between their combining weights.

This will be true of solutions that are seminormal, decinormal, etc.

MODEL EXAMPLE 52

How many grams of oxalic acid, $H_2C_2O_4 \cdot 2H_2O$, must there be in one liter to make a N/10 solution of the acid?

SOLUTION

M.W. of $H_2C_2O_4 \cdot 2H_2O = 126$. By Section 34, to make a normal solution one liter must contain 126/2 = 63 g. of the acid. To make a N/10 solution there must be 63/10 = 6.3 g. of the acid.

35. *Solutions depending upon Reactions Involved.*

In preparing some solutions for volumetric analysis, to determine the hydrogen equivalent in grams of a reagent the particular reaction in any given analysis must be considered.

Thus, when potassium permanganate is used as an oxidizing agent, the available oxygen must be taken into account, and the normal solution contains one-fifth of its molecular weight, $158/5 = 31.6$ grams, according to the reaction: $2KMnO_4 + 3H_2SO_4 = K_2SO_4 + MnSO_4 + 3H_2O + 5O$. Since $2KMnO_4 = 5O = 10H$, $1\ KMnO_4 = 5H$, and 1/5 of the M.W. must be taken to yield the equivalent of one gram of hydrogen.

MODEL EXAMPLE 53

What weight of potassium bichromate per liter must be used to make a normal solution, the equation being, $K_2Cr_2O_7 + 4H_2SO_4 = K_2SO_4 + Cr_2(SO_4)_3 + 4H_2O + 3O$.

SOLUTION

$K_2Cr_2O_7 = 3O = 6H$, and, therefore, one-sixth of the molecular weight of $K_2Cr_2O_7$ must be taken to yield one hydrogen equivalent to the liter.

$$M.W./6 = 294/6 = 49 \text{ grams.}$$

36. *Adjustment of Solutions to Standard Strength.*

When solutions cannot be prepared easily and directly by weighing the pure substances and diluting their solutions to definite strength,—to a liter, for example,—they may be obtained by standardizing a stronger solution and then diluting to the proper strength.

See Model Example 54.

It is frequently more advisable to use the method of Section 37(*b*) instead of trying to make adjustments which require great care and consume a great deal of time.

See Model Example 56.

MODEL EXAMPLE 54

Approximately 30 c.c. of con. sulphuric acid of sp. gr. 1.84 were added to 400 c.c. of water, cooled and diluted to about 900 c.c. 44.5 c.c. of this solution were required to neutralize 50 c.c. of the normal sodium carbonate solution. What adjustment must be made to make a normal acid solution?

SOLUTION

If the acid had been normal, 50 c.c. would have been required (Model Example 51). Therefore, the acid must be $50/44.5 = 1.1236$ N. This means that 1.1236 c.c. of sol. should contain the amount now contained in one c.c. If 12.36 c.c. of water are added to every 100 c.c. of the acid solution (= 123.6 c.c. per liter) the solution will be normal. Thus, the solution may be measured and diluted to correct bulk.

37. *Methods of Simplifying Calculations in Volumetric Analysis.*

(*a*) *Direct Reading of Percentages.*

It is often possible by the use of normal solutions and an appropriate weight of the substance under investigation to determine the percentage of the substance directly.

For example, it is very evident from Model Example 51 that 100 c.c. of any normal acid should saturate 5.3 grams of pure sodium carbonate. Therefore, 5.3 grams of the Na_2CO_3 under investigation can be dissolved in water, and the *number* of the c.c. required to saturate it will be the percentage of pure Na_2CO_3 dissolved. Proportional amounts must be taken for solutions of proportional strength.

Or, the solution of the acid may be made of such a strength that 100 c.c. will neutralize one gram of the sodium carbonate. From the equation $Na_2CO_3 + 2HCl = 2NaCl + H_2O + CO_2$, it is

$$\begin{array}{cc} 106 & 73 \\ 1.0000 & 100x \end{array}$$

evident that 100 c.c. of the acid will equal one gram of the Na_2CO_3 when 1 c.c. = .006887 gram, or 6.887 grams to the liter. Then the *number* of c.c. used will represent the percentage of Na_2CO_3 in one gram.

Similarly, if 1 c.c. of $KMnO_4$ is made equivalent to .010 gram of Fe, one gram of the substance containing the iron can be weighed out, and the *number* of the c.c. of $KMnO_4$ used will show the percentage of the iron.

MODEL EXAMPLE 55

One gram of sodium carbonate was dissolved in 100 c.c. of distilled water and 15.6 c.c. of normal H_2SO_4 were required to change the methyl orange in the solution to a pink color. What is the percentage of Na_2CO_3 in the solution?

SOLUTION

$$\begin{array}{ccccccccc} Na_2CO_3 & + & H_2SO_4 & = & Na_2SO_4 & + & H_2O & + & CO_2 \\ 106 & & 98. & & & & & & \\ x = .053 & & .049 & & & & & & \end{array}$$

1 c.c. of normal $H_2SO_4 = 98/2 \text{ x } 1000 = .049$ gram, which will neutralize .053 gram of Na_2CO_3. Therefore, $15.6 \text{ x } .053 = .8268$ gram of Na_2CO_3 in the solution. Since 1 gram was taken, there must have been $(.8268/1) \text{ x } 100 = 82.68\%$.

(*b*) *Factors for Calculations of Analysis.*

It is frequently unwise to make solutions exactly normal because of the difficulties and loss of time involved, and then the strength of the solution may be expressed in terms of a normal solution.

MODEL EXAMPLE 56

10 c.c. of a solution of HCl precipitated 1.567 grams of AgCl. What is the strength of the acid solution?

SOLUTION

$$\begin{array}{ccccccc} AgNO_3 & + & HCl & = & AgCl & + & HNO_3 \\ & & 36.5 & & 143.5 & & \\ & & .365 & & x = 1.435 & & \end{array}$$

$$10 \text{ c.c. of } N \cdot HCl = 36.5/1000 \text{ x } 10 = .365 \text{ gram.}$$

It is evident that this would precipitate 1.435 grams of AgCl. The 10 c.c. used precipitated 1.567 grams, and, therefore, it must have been (1.567/1.435 =) 1.092 N, and it may be labelled 1.092 N. HCl.

PROBLEMS

241. (*a*) How many grams to the liter will there be in a decinormal solution of nitric acid? (*b*) A solution of sulphuric acid contains 24.5 grams to the liter. What is the strength of the solution?

242. What weight of hydrogen will be set free by the action of 10 c.c. of normal sulphuric acid on zinc?

243. How much bicarbonate of soda must be heated to furnish sufficient sodium carbonate to make a liter of normal solution?

244. What weight of barium sulphate will be precipitated by adding an excess of sulphuric acid to 21.2 c.c. of N/10 solution of barium chloride?

245. Two grams of pure caustic potash are dissolved in 100 c.c. of distilled water; 5 c.c. of this solution will neutralize 20 c.c. of hydrochloric acid solution. Of what strength per liter is the hydrochloric acid?

246. From the equation $K_2Cr_2O_7 + 8HCl = 2KCl + 2CrCl_3 + 4H_2O + 3O$ calculate the weight necessary to make a N/10 solution of $K_2Cr_2O_7$.

247. How much N/10 acid solution will neutralize 30 c.c. of N/20 alkali solution?

248. From the equation $2KMnO_4 + 10FeSO_4 + 8H_2SO_4 = K_2SO_4 + 2MnSO_4 + 5Fe_2(SO_4)_3 + 8H_2O$ calculate the weight of $KMnO_4$ in a liter one c.c. of which equals .01 gram of iron?

249. 54.2 c.c. of a solution of nitric acid containing 25 grams to the liter are mixed with one gram of finely powdered limestone, and, after action ceases, the free acid neutralized with 2.3 c.c. of normal KOH. What is the per cent of $CaCO_3$ in the limestone?

$$CaCO_3 + 2HNO_3 = Ca(NO_3)_2 + H_2O + CO_2;$$
$$KOH + HNO_3 = KNO_3 + H_2O$$

250. How much iron can be reduced by 15 c.c. of a N/10 solution of stannous chloride?

$$SnCl_2 + 2FeCl_3 = SnCl_4 + 2FeCl_2$$

251. What weight of CaO must there be in a certain amount of $CaCO_3$ if the $CaCO_3$ is converted into CaC_2O_4 and then decomposed by 10 c.c. of a N/10 potassium permanganate solution?

$$2KMnO_4 + 5CaC_2O_4 + 8H_2SO_4 = K_2SO_4 + 2MnSO_4 + 5CaSO_4 + 10CO_2 + 8H_2O$$

252. What per cent of caustic soda must there be in 2 grams of purified caustic soda if 96 c.c. of N/2 H_2SO_4 are required to neutralize it?

253. What per cent of As_2O_3 is there in .125 gram of commercial arsenious oxide when 23.2 c.c. of a N/10 iodine solution is required to oxidize in presence of $NaHCO_3$?

$$As_2O_3 + 2I_2 + 10HNaCO_3 = 2Na_3AsO_4 + 4NaI + 10CO_2 + 5H_2O$$

254. To how many c.c. of normal sodium carbonate will 10 c.c. of .1275 N/H_2SO_4 be equivalent?

255. .3560 gram of common salt were dissolved in water and titrated with 61.4 c.c. of N/10 $AgNO_3$ solution. What was the percentage of NaCl in the salt?

256. 2.65 grams of moist sodium carbonate require 87.6 c.c. of a N/2 solution of hydrochloric acid to saturate it. What is the percentage of the water in the carbonate?

257. In standardizing a solution of potassium permanganate 68.1 c.c. saturated .6099 gram of ferrous-ammonium sulphate, $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$. What is the value of 1 c.c. of the solution in terms of iron?

258. (*a*) How many c.c. of sulphuric acid with a specific gravity of 1.8 and containing 86.9% of the acid must be diluted to one liter to make a N/2 acid solution?

(*b*) How many c.c. of the solution in (*a*) may be taken and diluted to one liter to make a N/20 solution of the acid?

259. A solution of NaOH was titrated against 1/10 normal

H_2SO_4. 12.1 c.c. of the acid neutralized 10 c.c. of the alkali. To what extent per liter must the NaOH be diluted to be N/10?

260. A decinormal solution of sodium arsenite is made by dissolving pure arsenious oxide in water, adding $NaHCO_3$, cooling and diluting to one liter. (*a*) How much As_2O_3 to the liter must be used to titrate free chlorine according to the equation:

$$As_2O_3 + 2Cl_2 + 10HNaCO_3 = 2Na_3AsO_4 + 10CO_2 + 5H_2O + 4NaCl$$

(*b*) How many grams of bleaching-powder ($CaOCl_2$) should be taken so that the number of c.c. of arsenite used will represent the percentage of available chlorine?

EXERCISE XVII

THERMOCHEMISTRY

38. *Thermal Units.*

(*a*) Gram-calorie, small calorie or "cal."

A gram-calorie is the amount of heat necessary to raise 1 gram of water through 1° C.

(*b*) Kilogram-calorie, large calorie or "Cal."

A kilogram-calorie is the amount of heat necessary to raise 1 kilogram of water through 1° C.

(*c*) British Thermal Unit or "B.T.U."

A "B.T.U." is the amount of heat necessary to raise 1 pound of water through 1° F.

(*d*) Pound-calorie or "pound-cal."

A "pound-calorie" is the amount of heat necessary to raise 1 pound of water through 1° C.

ILLUSTRATIONS

If 12 $\left\{\begin{array}{l}\text{grams}\\ \text{kilograms}\\ \text{pounds}\end{array}\right\}$ of carbon are burned with 32

$$\left.\begin{cases}\text{grams}\\ \text{kilograms}\\ \text{pounds}\end{cases}\right\}\text{ of oxygen to form } 44 \left\{\begin{matrix}\text{grams}\\ \text{kilograms}\\ \text{pounds}\end{matrix}\right\}\text{ of } CO_2,$$

$$\underset{12}{C} + \underset{32}{O_2} = \underset{44}{CO_2}\text{, there are set free } \left\{\begin{matrix}\text{97,200 gram-calories}\\ \text{97,200 kilogram-calories}\\ \text{97,200 pound-calories}\end{matrix}\right\}$$

if C.° are used. The 97,200 pound-calories would become 97,200 x 9/5 = 174,960 "B.T.U.," if F.° are used, since 1° C. = 9/5° F. (100° C. = 180° F.).

39. *Heat of Combustion.*

Heat of Combustion is the number of units of heat evolved during the combustion of one gram of a substance.

For example, if one gram of carbon is burned to CO_2, 8100 gram-calories of heat are set free. If 12 grams of carbon are burned to CO_2, 12 x 8,100 = 97,200 gram-calories are set free.

40. *Heat of Formation and Heat of Decomposition.*

Heat of Formation is the number of units of heat given out (or absorbed) in the formation of one gram-molecule of a compound from its elements.

Heat of Decomposition is the number of units of heat used or given out in the decomposition of one gram-molecule of a compound into its elements.

For example, when 2 grams of hydrogen and 16 grams of oxygen combine to form 18 grams of water, 68,400 gram-calories of heat are set free. Conversely, to separate 18 grams of water into 16 grams of oxygen and 2 grams of hydrogen 68,400 gram-calories of energy will be required.

41. *Heat of Neutralization.*

Heat of Neutralization is the number of units of heat evolved by neutralizing an acid with a base in aqueous solution with the formation of one gram-molecule of the salt.

For example, if 36.5 grams (= gr. mol. wt.) of HCl and 40 grams (= gr. mol. wt.) of NaOH are combined in aqueous solution, 58.5 grams (= gr. mol. wt.) of NaCl will be formed and 13,700 gram-calories of heat will be set free.

42. *Heat of Solution.*

Heat of Solution is the number of units of heat set free (or absorbed) when one gram-molecule of a substance is dissolved in a quantity of water so large that further dilution results in no additional thermal effect.

Thus, when 56 grams of CaO are dissolved in a very dilute solution, 18,300 gram-calories of heat are evolved.

43. *Exothermic Reactions.*

A reaction in which heat is evolved is called *exothermic*, as $C + O_2 = CO_2 + 97{,}200$ gram-calories.

44. *Endothermic Reactions.*

A reaction in which heat is absorbed is called *endothermic*, as in the formation of acetylene, C_2H_2. 57,000 gram-calories of heat are absorbed.

45. *Law of Hess.*

The final thermal effect of a reaction which is reached through intermediate phases is equal to that obtained when the reaction occurs in one phase.

This law suggests the determination of the heat of formation of compounds indirectly when direct methods cannot be used.

MODEL EXAMPLE 57

Calculate the heat of formation of carbon monoxide from the following data:

$$\begin{aligned} C + O_2 &= CO_2 + 97{,}200 \text{ gram-calories} \\ 2CO + O_2 &= 2CO_2 + 136{,}800 \text{ gram-calories} \end{aligned}$$

SOLUTION

To burn C to CO_2: 97,200 gram-calories are set free
To burn CO to CO_2: 68,400 gram-calories are set free

Therefore, 28,800 gram-calories must be set free in burning C to CO.

MODEL EXAMPLE 58

Calculate the heat energy made available by changing 12 grams of carbon into "water gas," from the following data:

$$C + O_2 = CO_2 + 97{,}200 \text{ "cals."}$$
$$C + O = CO + 28{,}800 \text{ "cals."}$$
$$2H_2 + O_2 = 2H_2O + 136{,}800 \text{ "cals."}$$

SOLUTION

To form "water gas": (1) $C + H_2O = CO + H_2$.
Combustion of "water gas": (2) $CO + H_2 + O_2 = CO_2 + H_2O$

Heat energy available in $CO = 97{,}200 - 28{,}800 = 68{,}400$ "cals.," as per Model Example 57.

The heat energy necessary in (1) to decompose the 18 grams of steam, or 68,400 "cals.," will be regained when H_2 in (2) is burned. Therefore, 68,400 "cals." will be available from the CO if the gases are consumed immediately after formation.

MODEL EXAMPLE 59

Calculate the amount of heat set free by the reaction of powdered aluminum and ferric oxide in the Gold-Schmidt Process, from the following data:

Heat of formation of $Al_2O_3 = 392{,}600$ "cals."
Heat of formation of $Fe_2O_3 = 195{,}600$ "cals."

SOLUTION

$$Fe_2O_3 + 2Al = Al_2O_3 + 2Fe$$

Heat of formation of $Al_2O_3 =$	392,600	"cals."
Heat of decomposition of Fe_2O_3 (Section 40) $=$	195,600	"cals."
Gain in heat energy $=$	197,000	"cals."

MODEL EXAMPLE 60

Calculate the amount of heat of formation of starch from the following data:

$$2H_2 + O_2 = 2H_2O + 136{,}800 \text{ “cals.”}$$
$$C + O_2 = CO_2 + 97{,}200 \text{ “cals.”}$$

Heat of combustion of one gram of starch = 4,220 “cals.”

SOLUTION

$$C_6H_{10}O_5 + 6O_2 = 5H_2O + 6CO_2$$

Heat of formation of $5H_2O$ = 342,000 “cals.”
Heat of formation of $6CO_2$ = 583,200 “cals.”
$\overline{925{,}200}$ “cals.”

Heat of combustion of 142 grams (1 gr. mol. wt.) of starch = 596,400 “cals.”

Loss in heat energy: 925,200 — 596,400 = 328,800 “cals.,” which represents the heat energy to decompose the starch and is equal to the heat of formation. (Section 40.)

MODEL EXAMPLE 61

Calculate the heat of neutralization of caustic potash with hydrochloric acid from the following data:

$$2K + O_2 + \text{dil. sol.} = 2KOH + 234{,}200 \text{ “cals.”}$$
$$H_2 + Cl_2 + \text{dil. sol.} = 2HCl + 78{,}800 \text{ “cals.”}$$
$$2K + Cl_2 + \text{dil. sol.} = 2KCl + 202{,}400 \text{ “cals.”}$$
$$2H_2 + O_2 = 2H_2O \text{ (liquid)} + 136{,}800 \text{ “cals.”}$$

SOLUTION

$$KOH \text{ sol.} + HCl \text{ sol.} = KCl \text{ sol.} + H_2O$$

Heat of decomposition of KOH sol. (Sec. 40) = 117,100 “cals.”
Heat of decomposition of HCl sol. (Sec. 40) = 39,400 “cals.”
$\overline{156{,}500}$ “cals.”
Heat of formation of KCl sol. = 101,200 “cals.”
Heat of formation of H_2O (liq.) = 68,400 “cals.”
$\overline{169{,}600}$ “cals.”

The gain 169,600 — 156,500 = 13,100 “cals.,” due to the heat of neutralization.

PROBLEMS

261. (*a*) What heat will be required to make 640 kilograms of calcium carbide, using the following data:

$$2Ca + O_2 = 2CaO + 263{,}000 \text{ "cals."}$$
$$2C + O_2 = 2CO + 57{,}600 \text{ "cals."}$$
$$Ca + 2C = CaC_2 - 6{,}250 \text{ "cals."}$$

(*b*) What heat would be evolved by the action of water on the 640 kilograms of the calcium carbide of (*a*), the following additional data being given?:

$$Ca + O_2 + H_2 = Ca(OH)_2 + 215{,}600 \text{ "cals."}$$
Heat of formation of $C_2H_2 = -54{,}750$ "cals."
$$2H_2 + O_2 = 2H_2O + 136{,}800 \text{ "cals."}$$

262. Calculate the heat units evolved when black cupric oxide is reduced by powdered aluminum, if the heats of formation of CuO and Al_2O_3 are respectively 37,700 and 392,600 gram-calories.

263. How much heat will be set free by the reaction of gram-molecular weights of zinc and sulphuric acid in dilute solution? Heats of formation in dilute solution: H_2SO_4, 210,000 "cals."; $ZnSO_4$, 248,000 "cals."

264. Calculate the heat of formation of acetylene from the following data: heat of combustion of one gram-molecule of acetylene, 304,200 "cals."; $C + O_2 = CO_2 + 97{,}200$ "cals."; $2H_2 + O_2 = 2H_2O + 136{,}800$ "cals."

265. Calculate the heat of formation of CuO, if 30,700 gram-calories of energy are set free when CuO is reduced by hydrogen. $2H_2 + O_2 = 2H_2O + 136{,}800$ "cals."

266. Calculate the heat of neutralization of caustic soda and hydrochloric acid from the following data:

$2Na + Cl_2 + aq. = 2NaCl\ aq. + 193{,}800$ "cals." (aq. = dil. sol.).
$2Na + O_2 + H_2 + aq. = 2NaOH\ aq. + 225{,}000$ "cals."
$H_2 + Cl_2 + aq. = 2HCl\ aq. + 78{,}800$ "cals."
$2H_2 + O_2 = 2H_2O + 136{,}800$ "cals."

267. Calculate the heat of formation of sodium chloride in

dilute solution, if NaOH aq. + HCl aq. = NaCl aq. + H_2O + 13,400 "cals.," and using necessary data from problem 266.

268. (*a*) What is the difference in heat units set free between the reaction of solutions of caustic potash and hydrochloric acid, and the passing of hydrochloric gas into a solution of caustic potash?

(*b*) What does this heat represent?

Data: $2K + O_2 + H_2 + aq. = 2KOH\ aq. + 234{,}200$ "cals."
$H_2 + Cl_2 + aq. = 2HCl\ aq. + 78{,}800$ "cals."
KCl aq. = 101,200 "cals."
$H_2O =$ 68,400 "cals."
$H_2 + Cl_2 = 2HCl + 44{,}000$ "cals."

269. Calculate the difference in the heat set free by the action of HCl and H_2SO_4 on FeS.

Data: Heat of formation of FeS = 24,200 "cals."
Heat of formation of HCl aq. = 39,400 "cals."
Heat of formation of H_2SO_4 aq. = 210,200 "cals."
Heat of formation of $FeCl_2$ aq. = 101,100 "cals."
Heat of formation of $FeSO_4$ aq. = 234,900 "cals."
Heat of formation of H_2S gas = 4,800 "cals."

270. How much heat will be set free in slaking 100 grams of quick lime?

Data: $2Ca + O_2 = 2CaO + 263{,}000$ "cals."
$2H_2 + O_2 = 2H_2O + 136{,}800$ "cals."
$Ca + O_2 + H_2 = Ca(OH)_2 + 215{,}600$ "cals."

MISCELLANEOUS PROBLEMS

271. (*a*) What will be the area of a filter paper 9 cm. in diameter?

(*b*) If a cylindrical measure is 3.0 cm. in diameter, how high must it be to hold 100 c.c.?

272. (*a*) A bottle holds 75 oz. of water. What is its capacity in c.c.?

(*b*) To how many grams will an 8 oz. weight be equivalent?

273. Calculate the molecular weights of the following: (i) NaCl, (ii) H_2CO_3, (iii) $CuSO_4 \cdot 5H_2O$.

274. Calculate the percentage compositions of the following: (i) HNO_3, (ii) FeS_2.

275. (*a*) How many tons of limestone will make 500 tons of lime?

(*b*) What weight of potassium bromide must be used to make 100 grams of bromine?

276. How much cupric oxide can be obtained by heating 48.3 grams of cupric nitrate, $Cu(NO_3)_2 \cdot 3H_2O$?

277. (*a*) Zinc melts at about 430° C. Express this temperature in Fahr. degrees.

(*b*) To what temperature on the Centigrade scale does 40° F. correspond?

278. A certain stone block weighs 150 lbs. per cu. ft. What is the weight of a cu. meter of the same block in kilograms?

279. By what factor must the weight of $BaSO_4$ obtained in an analysis be multiplied to represent the weight (*a*) of the S, (*b*) of the SO_3, of the substance?

280. What is the percentage of iron in hematite, Fe_2O_3, if the ore is 96.5% pure?

281. How many gram-molecules of oxygen can be obtained by heating 1225 grams of potassium chlorate?

282. (*a*) How many liters at 0° C. and under 760 mm. pressure would the oxygen of problem 281 occupy?

(*b*) What volume at 15° C. and under 760 mm. would the same gas occupy?

283. Find the weight of zinc which could be dissolved by 250 grams of a solution of hydrochloric acid containing 27% by weight of HCl?

284. (*a*) Ten liters of hydrogen sulphide weigh 15.22 grams under N.T.P. conditions. What is its vapor density?

(*b*) How many c.c. of oxygen will result from the decomposition of ten liters of ozone?

285. To what temperature must an open vessel be heated to drive out one-tenth of the air it contained at 18° C.?

286. How many liters of ammonia gas under standard conditions of temperature and pressure could be obtained from 100 grams of ammonium sulphate?

287. Calculate the density of ethylene, C_2H_4, with reference to (*a*) air, (*b*) hydrogen, (*c*) oxygen.

288. Hydrogen was burned in chlorine and 21.9 grams of hydrochloric acid gas were produced. How much zinc must be used to generate the hydrogen?

289. How much "choke damp," CO_2, will be formed by the explosion of 750 cu. ft. of methane or marsh gas?

290. A tube contains 21.5 c.c. of hydrogen under a pressure of 72.5 cm. and at a temperature of 15° C. What will be the pressure on the tube when the gas is heated to 315° C.?

291. Dumas found that 100 parts of Iceland Spar, $CaCO_3$, yielded 56 parts of CaO. What is the atomic weight of calcium when $C = 12$ and $O = 16$?

292. (*a*) Calculate the weight of a liter of air under normal conditions, regarding its composition by volume as follows: nitrogen, 78%; oxygen, 21%; argon, .9%.

(*b*) What would a liter of air weigh if its composition were N_4O?

293. What quantities of the following substances in every 100 c.c. must exist to make a half-normal solution: (i) NH_4Cl, (ii) $Ba(OH)_2$, (iii) $Na_2S_2O_3 \cdot 5H_2O$?

294. (*a*) A compound analysis: carbon, 40%; hydrogen, 6.7%; oxygen, 53.3%. What is its simplest formula?

(*b*) The vapor density of a gas is 22. Its percentage composition is as follows: carbon 81.82%; hydrogen, 18.18%. What is its formula?

295. A solution of potassium permanganate was standardized and each c.c. was found to be equal to .01099 gram of iron. To how much CaO would this be equivalent according to the following equations:

$$10FeSO_4 + 2KMnO_4 + 8H_2SO_4 = 5Fe_2(SO_4)_3 + 2MnSO_4 + K_2SO_4 + 8H_2O$$

$$5CaC_2O_4 + 2KMnO_4 + 8H_2SO_4 = 5CaSO_4 + 2MnSO_4 + K_2SO_4 + 8H_2O + 10CO_2$$

296. How many calories of heat would result from the combustion of 10 cu. meters of carbon monoxide at 0° C. and 760 mm. pressure?

$$2CO + O_2 = 2CO_2 + 136{,}800 \text{ cals.}$$

297. What space will 230 grams of ethyl alcohol at 80° C. and 76 cm. occupy?

298. How many cu. ft. of CO_2 under S.T.P. conditions would result from the combustion of the acetylene formed by action of water on 10 lbs. of calcium carbide?

299. (*a*) How much sulphur would be required to make 100 lbs. of carbon disulphide?

$$C + 2S = CS_2.$$

(*b*) How many pounds of each constituent would be required to make 500 pounds of gunpowder containing saltpetre, 75 parts; sulphur, 11 parts; charcoal, 14 parts?

300. (*a*) What weight of quicklime would be required to set free the NH_3 in 30.4 grams of ammonium sulphate?

(*b*) What volume would this gas occupy at 18° C. and 730 mm. pressure?

301. If the air in a room contains 5 vols. of CO_2 in every 10,000 volumes of air, calculate (*a*) the volume at 0° and 760 mm., and (*b*) the weight, the room being 10 x 8 x 4 meters.

302. (*a*) How many c.c. in 64 fluid ounces?

(*b*) How many grams in 214 kilograms?

(*c*) Find the area of a filter paper 10 cm. in diameter.

303. (*a*) How much antimony can be obtained from one ton of stibnite if the ore is 55% pure?

(*b*) How many kilograms of carbon disulphide can be made from 1000 kilograms of sulphur if 90% of the sulphur is used?

304. (*a*) The volume of a gas was measured at 15° C. If the pressure remains the same, at what temperature will its volume be doubled?

(*b*) Two volumes of arsine may be decomposed into one-half volume of arsenic vapor and three volumes of hydrogen. How many atoms in the molecule of arsenic?

305. If one liter of ammonium hydroxide with a specific gravity of .91 contains 25% of NH_3, what volume of ammonia gas at 18° C. and 740 mm. pressure could be obtained from it?

306. When 10 grams of crystallized barium chloride are heated, there is a loss of 1.475 grams of water. How many molecules of water of crystallization did it contain?

307. How mucn magnesium chloride, $MgCl_2 \cdot 6H_2O$, can be obtained from 2224 lbs. of carnallite, $MgCl_2 \cdot KCl \cdot 6H_2O$?

308. What will be the final volume if 1500 c.c. of air measured at 16° C. and 754 mm. pressure are cooled to —10° C. under a pressure of 720 mm.?

309. (*a*) What weight of silver will be precipitated from a solution of silver nitrate by 52.4 grams of zinc?

(*b*) How much silver will be deposited by a current which will deposit 5 grams of copper in a given time?

310. How much hydrochloric acid solution containing 12.5% by weight of HCl will be needed to set free 112 liters of chlorine, under S.T.P. conditions, by reaction with manganese dioxide?

311. One liter of air was passed over a quantity of hot copper. The copper gained .2832 gram in weight. What was the percentage of oxygen by weight in the air? (A liter of air = 1.293 grams.)

312. Without using atomic weights calculate the percentage of oxygen in sulphur dioxide from the fact that sulphur trioxide contains 60% of oxygen.

313. How much ammonium chloride must be mixed with sodium nitrite to make 2.1 grams of nitrogen?

$$NH_4Cl + NaNO_2 = NaCl + 2H_2O + N_2$$

314. Calculate the volume of hydrochloric acid solution, density 1.12 and containing 21.5% of pure acid, that is required to make 500 grams of barium chloride from the carbonate?

315. How much nickel would be deposited electrolytically from nickel sulphate by a current sufficient to deposit 10 grams of copper from copper sulphate?

316. 21 c.c. of chlorine and 12.6 c.c. of hydrogen are mixed and exploded. What gases will remain, and what will be their volumes?

317. How much heat will be required to reduce 151 grams of tin dioxide? Data:

Heat of formation of $SnO_2 = 141,300$ cals.
Heat of formation of $CO_2 = 68,400$ cals.

318. A solution of silver nitrate contains 17 grams of $AgNO_3$ to the liter. How many c.c. of a decinormal solution of potassium chloride will be required to precipitate the silver contained in 15.6 c.c. of the nitrate solution?

319. Calculate the weight of 1000 liters of air measured at 0° C. and 760 mm. pressure, and containing 21% of O and 79% of N by volume.

320. .5 gram of pure silver dissolved in nitric acid is precipitated by potassium bromide and yields .87 gram of silver bromide. If silver has an atomic weight of 108, find the atomic weight of bromine.

321. (*a*) How many kilograms of sulphur dioxide can be obtained from 100 kilograms of iron pyrites which is 94% pure? $4FeS_2 + 11O_2 = 2Fe_2O_3 + 8SO_2$

(*b*) How many cu. meters under standard conditions of temperature and pressure would this gas occupy?

322. (*a*) Calculate the percentage of chromic oxide, Cr_2O_3, in chromite, $FeCr_2O_4$.

(*b*) Calculate the percentage of phosphorus in $Ca_3(PO_4)_2$.

323. How many grams of stannous chloride must there be in one liter to make 1 c.c. of the solution correspond to .008 gram of Fe_2O_3 according to the equations:

$$Fe_2O_3 + 6HCl = 2FeCl_3 + 3H_2O$$
$$2FeCl_3 + SnCl_2 = 2FeCl_2 + SnCl_4$$

324. (*a*) In the analysis of an iron ore there was found 61.59% of metallic iron. How much ferric oxide, Fe_2O_3, in the ore does this represent?

(*b*) One gram of a limestone yields on analysis .5268 gram of CaO. What is the percentage of $CaCO_3$ in the limestone?

325. (*a*) 1.66 grams of potassium iodide are added to a solution of silver nitrate. How many grams of silver iodide will be precipitated?

(*b*) How many kilograms of salt must be used to prepare 54.2 kilograms of mercuric chloride?

$$2NaCl + HgSO_4 = Na_2SO_4 + HgCl_2$$

326. Fifteen grams of Glauber's salt were found to contain 7.05 grams of water. How many molecules of water of crystallization did the salt contain?

327. How many liters of hydrobromic acid gas at 0° C. and 760 mm. can be prepared from 12.4 grams of red phosphorus?

$$P + 3Br = PBr_3;\ 3H_2O + PBr_3 = H_3PO_3 + 3HBr$$

328. (*a*) How much sulphur trioxide in .2345 gram of barium sulphate?

(*b*) By what factor must $BaSO_4$ be multiplied to get the SO_3?

329. (*a*) How much sodium carbonate would be needed to decompose 8.6 grams of gypsum, $CaSO_4 \cdot 2H_2O$?

(*b*) In the analysis of a zinc ore 2.282 grams of ore were taken and .476 gram of zinc were obtained. What per cent of zinc in the ore?

330. (*a*) How many atoms of hydrogen and of oxygen would result from the decomposition of *n* molecules of water?

(*b*) The vapor density of ozone is 24. What is the molecular formula?

331. (*a*) What is the simplest formula of a substance containing 89.6% of bismuth and 10.4% of oxygen?

(*b*) What is the simplest formula for leucopyrite if it analyzes as follows: iron, 27.2%; arsenic, 72.8%?

332. One metric ton of gunpowder containing 75% by weight of saltpetre is made. What weight of Chile saltpetre will be required according to the equation:

$$KCl + NaNO_3 = KNO_3 + NaCl?$$

333. A spherical vessel holds 4190.47 grams of water at 4° C. What is the diameter of the vessel?

334. When 15 grams of cobaltous oxide, CoO, are reduced in a current of hydrogen 11.8 grams of cobalt are obtained. What is the atomic weight of cobalt if $O = 16$?

335. What is the percentage of chlorine in a solution of bleaching powder which has a sp. gr. of 1.11 and contains 68.4 grams of chlorine to the liter?

336. What would be the pressure in atmospheres of 200 grams of steam vapor at a temperature of 250° C. if confined in a space of 25 liters capacity?

337. (*a*) What is the specific gravity of a liquid if 25 liters of it weigh 31 kilograms?

(*b*) What is the weight of 1500 c.c. of oil of vitriol whose specific gravity is 1.83?

338. How much carbon dioxide at 18° C. and 756 mm. pressure would result from the combustion of 10,000 cu. ft. of illuminating gas of the following composition: hydrogen, 31%; methane, 25%; ethylene, 10%; carbon monoxide, 30%; nitrogen, 2%; hydrogen sulphide, 2%?

339. How many lbs. of (i) Chile saltpetre, $NaNO_3$, (ii) kainite, $KCl \cdot MgSO_4 \cdot 3H_2O$, and (iii) bonemeal, $Ca_3(PO_4)_2$, must be used to make one ton of fertilizer containing 1.5% of nitrogen, 5% of potassium and 2% of phosphorus?

340. (*a*) How many kilograms of calcium carbide and (*b*) how many cu. meters of nitrogen at 20° C. and 754 mm. pressure must be used to make 25 kilograms of calcium cyanamide?

$$CaC_2 + 2N = CaNNC + C$$

341. What effect would be noticed in the pressure if 2500 c.c. of ozone at 0° and 760 mm. pressure are converted into oxygen at a temperature of 400° C., the volume being constant?

342. 11.2 c.c. of a normal solution of sodium carbonate are required to neutralize 10 c.c. of a HNO_3 solution. How many c.c. of water must be added to each 100 c.c. of the acid solution to make it normal?

343. If 100 c.c. of a centinormal solution of sodium chloride is added to a N/10 solution of silver nitrate, how much silver chloride will be precipitated?

344. (*a*) A gas has the formula C_7H_{16}. How much heavier than air is it? (Liter of air = 1.293 grams.)

(*b*) A liter of a gas weighs 12.75 grams. A liter of hydrogen under the same conditions weighs .085 gram. The atomic weight of the element is 75. What is the molecular formula of the gas if its symbol is designated by R?

345. A definite current of electricity deposits 2 grams of copper from a solution of copper sulphate in a given time. What volume of hydrogen at 0° and 760 mm. would be set free from water, acidulated with sulphuric acid, in the same time?

346. How many grams of sodium acetate will make 10 liters of methane measured under standard conditions of temperature and pressure?

$$NaC_2H_3O_2 + NaOH = Na_2CO_3 + CH_4$$

347. From 12.25 grams of a substance are obtained 4.8 grams of oxygen. (*a*) What per cent of oxygen does it contain? (*b*) The formula-weight or gram-molecular weight of the substance is 122.5 grams. How many atoms of oxygen does it contain?

348. An acetylene generator furnishes ½ of a cu. m. of gas under a pressure of 2 atmospheres and a temperature of 17° C. daily for 365 days. How much calcium carbide will be required, neglecting waste?

349. 100 cu. ft. of illuminating gas under normal pressure and at a temperature of 30° C. is forced into a storage cylinder of 10 cu. ft. capacity and cooled to 15° C. What pressure expressed in atmospheres will be exerted on the cylinder?

350. 420 grams of caustic soda are dissolved in pure water, and the solution is diluted to one liter. The sp. gr. of the solution is 1.345. What per cent of NaOH does it contain?

351. What must be the formula of an oxide of copper if one gram of copper yields 1.25 grams of the oxide?

352. Without using atomic weights calculate the percentage of nitrogen in nitrogen trioxide from the fact that nitrous oxide contains 36% of oxygen.

353. 36 c.c. of oxygen were partially changed to ozone and the volume was diminished to 30 c.c. It was then gently heated and the former volume restored. What was the percentage of the ozone in the volume (30 c.c.) of the mixture?

354. In the determination of the iron in one gram of an iron ore 73 c.c. of $KMnO_4$ solution were used to oxidize the iron. What per cent of Fe_2O_3 would this represent if each c.c. of the solution is equivalent to .0066 gram of iron?

355. (*a*) A block of rock salt, 40 x 40 x 40 cm., weighs 136.96 kilograms. What is its specific gravity?

(*b*) A man weighs 150 lbs. What is his weight in kilograms?

356. How much more nitric acid by weight could be made from 500 grams of $NaNO_3$ than from the same quantity of KNO_3?

357. 5 grams of the chloride of an univalent element contain 47.6% of chlorine. If the atomic weight of chlorine is 35.5, what is the atomic weight of the other element?

358. 5.6 liters of hydrogen at 0° and 760 mm. are passed over a large quantity of cupric oxide, heated to redness, in a glass tube. How much will the tube lose in weight?

359. An electric current of definite strength is passed through solutions of cuprous chloride and cupric chloride. In one hour there are deposited from the cuprous solution .2165 gram of copper. How much copper would there be deposited from the cupric solution in the same time?

360. A gas analyzes: nitrogen, 36.84%; oxygen, 63.16%. Its vapor density is 38. What is the formula of the gas?

361. How much acetic acid can be made from 100 liters of alcohol of sp. gr. .98 and containing 10% of alcohol, assuming 10% loss? $C_2H_6O + 2O = C_2H_4O_2 + H_2O$

362. How much heat will be set free by the action of 49 grams of sulphuric acid on calcium carbonate, the following data being given:

Heat of formation of $CaCO_3 = 273{,}800$ cals.
Heat of formation of $H_2O = 68{,}400$ cals.
Heat of formation of $CaSO_4 = 321{,}800$ cals.

Heat of formation of $CO_2 =$ 97,200 cals.
Heat of formation of $H_2SO_4 =$ 210,000 cals.

363. (*a*) The density of iodine vapor with reference to air is 8.72. What is its density with reference to hydrogen?

(*b*) What is the molecular formula for iodine?

364. What volumes of (*a*) carbon dioxide and (*b*) water vapor at 250° C. and 760 mm. pressure will be formed by burning 1000 kilograms of powdered coal containing the following combustibles: hydrogen, 5%; carbon, 74%?

365. How many kilograms of bauxite of the formula, $Al_2O_3 \cdot 2H_2O$, must be used to yield 10 kilograms of aluminum?

366. A normal acid solution is used to determine the amount of Na_2CO_3 in one gram of the substance. What would be the percentage of error in terms of Na_2CO_3 if an error of one drop of the acid solution, amounting to .05 c.c., is made in the delivery from the burette?

367. From 4.25 grams of LiCl 14.36 grams of AgCl are obtained. If $Ag = 108$ and $Cl = 35.5$, what is the atomic weight of lithium?

368. How much space would 1000 grams of ammonia gas occupy at 18° C. and 75.2 cm. pressure?

369. How much hydrochloric acid solution containing 20% of HCl will generate sufficient hydrogen sulphide from ferrous sulphide to precipitate all of the $CuSO_4$ in a solution made by dissolving 5 grams of blue vitriol in water?

370. The molecular weight of a gas is 74. 64.86% of the gas is carbon, 13.51% is hydrogen and 21.62% is oxygen. What is the gas?

371. (*a*) How much copper in one ton of ruby copper, Cu_2O?

(b) Find the percentage composition of the following: (i) CO, (ii) NH_4OH, (iii) $Na_2B_4O_7 \cdot 10H_2O$.

372. What must be the capacity of a vessel to hold 5 kilograms of a liquid whose specific gravity is 1.24?

373. In the analysis of a substance .0065 gram of $Mg_2P_2O_7$ were obtained. To what per cent of MgO does this correspond if one gram of the substance was taken?

374. (*a*) What weight of cupric oxide must be used to make one kilogram of cupric chloride, $CuCl_2 \cdot 2H_2O$?

(*b*) How much more hydrochloric acid by weight can be obtained from 100 grams of sodium chloride than from the same weight of potassium chloride?

375. What will 10 liters of a mixture of nitrogen and carbon dioxide weigh if there is 80% of nitrogen and 20% of carbon dioxide, taken under N.T.P. conditions?

376. How many cu. meters of chlorine at 0° C. and 760 mm. pressure can be obtained from 100 kilos. of bleaching-powder which has 30% by weight of available chlorine?

377. (*a*) In standardizing a potassium permanganate solution 78.5 c.c. of the solution were needed to oxidize .1679 gram of iron. What is the value of one c.c. of the solution in terms of iron?

(*b*) Suppose one drop more than enough was used to oxidize the iron. What error per gram would be introduced, one drop being equal to .05 c.c.?

378. (*a*) In the determination of the alkalis in a clay .0207 gram of NaCl was obtained. To how much Na_2O in one gram of the clay does this correspond?

(*b*) From 5 grams of lead ore taken for assay a lead button weighing 3.165 grams of lead was obtained. What is the percentage of lead in the ore?

379. How many cu. ft. of "water gas" will be formed from 100 lbs. of steam if the gases are measured at 25° C. and 75 cm. pressure? $C + H_2O = CO + H_2$

380. By how much would the volume of a gas be changed if its temperature is decreased from 27° C. to —23° C. with no change in pressure?

381. Ten grams of copper are obtained from copper oxide by means of hydrogen. How much steam at 100° C. and 750 mm. would have to be used to furnish this amount of hydrogen by passing the steam over heated iron filings?

382. A quantity of caustic potash solution required 23.4 c.c. of normal HCl solution to neutralize it. What is the weight of KOH in the solution?

383. A solution of ammonium hydroxide has a specific gravity of .89 and contains 31.75% of NH_3. (*a*) How many grams

of ammonia gas can be obtained from two liters of the solution, (*b*) and what will be the volume of the gas under normal conditions of temperature and pressure?

384. Find the proportions (*a*) by weight and (*b*) by volume with which propane, C_3H_8, will combine with oxygen.

385. How much heat will be required to make 1000 liters (under S.T.P. conditions) of ammonia gas from sal ammoniac and slaked lime? Data:

Heat of formation of $Ca(OH)_2$ = 215,600 cals.
Heat of formation of NH_4Cl = 76,800 cals.
Heat of formation of $CaCl_2$ = 170,000 cals.
Heat of formation of NH_3 = 12,000 cals.
Heat of formation of H_2O = 68,400 cals.

386. What weight of metallic zinc will be dissolved in precipitating 2.5 grams of metallic silver from a solution of silver nitrate?

387. (*a*) What volume of (i) hydrogen and (ii) oxygen could be obtained from 1 gram of water at 4° C., if the gases are measured under normal conditions?

(*b*) What volume would the water occupy as steam at 100° C. and under normal pressure?

388. What volumes of gases under N.T.P. conditions would result from the complete combustion of 10 grams of sulphur and 15 grams of charcoal?

389. (*a*) What weight of crystallized sodium carbonate, $Na_2CO_3 \cdot 10H_2O$, will combine with 14.6 grams of hydrochloric acid?

(*b*) What volume of carbon dioxide measured at 23° C. and 780 mm. pressure will be set free?

390. (*a*) How much phosphorus can be obtained from 50 grams of bone black, 70% of which is calcium phosphate?

(*b*) What is the weight in kilograms of a carboy of sulphuric acid of 45 liters capacity if the specific gravity of the acid is 1.82?

391. (*a*) When 10 grams of a univalent metal are heated in a stream of chlorine 13.29 grams of its chloride are formed. What is the atomic weight of the metal?

(*b*) The chloride of a bivalent metal contains 34.1% of chlorine. What is the atomic weight of the element?

392. How many liters will 5 gram-molecules of hydrogen occupy at 21° C. and 756 mm. pressure?

393. Ammonia gas is passed into water, yielding a solution of density .93 and containing 18.6% by weight of NH_3. (*a*) What is the weight of ammonia per c.c., and (*b*) what will be the volume of the solution necessary to neutralize 20 grams of sulphuric acid?

394. The temperature of a gas is 15° C. To what temperature must it be heated to drive off 1/5 of the volume, the pressure being constant?

395. How much sodium sulphate will result from the action of 500 c.c. of sulphuric acid on common salt, the acid having a density of 1.5 and containing 60% by weight of the acid?

396. How much bleaching powder, $CaOCl_2$, can be formed from 1000 lbs. of slaked lime?

397. If 1 c.c. of $KMnO_4$ solution is equivalent to .007 gram of iron, to what weight of Mn will each c.c. of the same solution be equivalent?

$$10FeSO_4 + 2KMnO_4 + 8H_2SO_4 = 5Fe_2(SO_4)_3 + K_2SO_4 + 2MnSO_4 + 8H_2O$$

$$3MnSO_4 + 2KMnO_4 + 2H_2O = 5MnO_2 + K_2SO_4 + 2H_2SO_4$$

398. A coal contains 2.5% of hydrogen, 85% of carbon and 12.5% of ash. How many cu. ft. of oxygen under N.T.P. conditions will be required to burn one ton of the coal?

399. How many kilograms of sulphuric acid would be required to make one metric ton of superphosphate of lime?

400. How much manganese dioxide would form sufficient chlorine to liberate 76.2 grams of iodine from a solution of potassium iodide?

APPENDIX

ANSWERS

1. 5,867 g.
2. 19.64 sq. cm.
3. 8.18 l.
4. 10 kilos.
5. 10 kilos.
6. 1 metric ton.
7. (*a*) 42428.6 l.
    (*b*) 42.43 metric tons.
8. (*a*) 756.92 mm.
    (*b*) 75.69 cm.
9. .00219 g.
10. 2.032 cm.
11. (*a*) 29.57 c.c.
    (*b*) 946.35 c.c.
12. 67.64 fl. oz.
13. 14,785 c.c.
14. 3.38 fl. oz.
15. 9.46 kilos.
16. (*a*) 37°.8 C.
    (*b*) 0° C.
    (*c*) — 17°.8 C.
    (*d*) — 40° C.
    (*e*) — 73°.3 C.
17. (*a*) 64°.4 F.
    (*b*) 32° F.
    (*c*) 5° F.
    (*d*) — 40° F.
    (*e*) — 148° F.
18. — 40
19. — 459°.4 F.
20. (*a*) — 170°.1 F.
    (*b*) 109°.1 F.
21. (*a*) 293°
    (*b*) 93°
22. (*a*) — 38°.9 F.
    (*b*) 674°.6 F.
23. 0°.4 F.
24. 2,646° F
25. 57°.6 F.
26. 34
27. 44
28. 98
29. 53.5
30. 202
31. 100
32. 322
33. 948
34. 444
35. 209
36. H : 2.04%
    S : 32.65%
    O : 65.31%
37. Fe : 72.41%
    O : 27.59%
38. Na : 27.38%
    H : 1.19%
    C : 14.29%
    O : 57.14%
39. Pb : 62.54%
    N : 8.46%
    O : 29.00%
40. N : 21.21%
    H : 6.06%
    S : 24.24%
    O : 48.48%
41. 43.48%
42. 70%
43. 53.33%

44. 56%
45. 79.07%
46. 18.16%
47. 34.26%
48. 98.61%
49. 87.99%
50. 46.72%
51. 96 g.
52. 11.15 g.
53. 18.33 g.
54. 2.76 g.
55. 1 g.
56. 2 g.
57. (*a*) 24.72 g.
    (*b*) 82.82 g.
58. (*a*) 1174.5 g.
    (*b*) 1030.5 g.
59. 1.7857
60. 1.0598
61. (*a*) .70
    (*b*) 57.48%
62. 34 g.
63. 58.18 g.
64. 28 g.
65. (*a*) 37.5 g.
    (*b*) H_2O : 4.8 g.
    NO : 4.0 g.
66. 12.56 kilos.
67. (*a*) 28.72 g.
    (*b*) 42.00 g.
68. 3.76 g.
69. (*a*) 39.71 g.
    (*b*) 18.86 g.
70. (*a*) 14.20 g.
    (*b*) 35.00 g.
71. (*a*) 99.80 g.
    (*b*) 81.67 g.
72. (*a*) 17.40 g.
    (*b*) 66.60 g.
73. 99 g.
74. 35.75 g.
75. (*a*) 71.60 g.
    (*b*) 10.70 g.
76. (*a*) 20 l.
    (*b*) 10 l.
77. 5 l.
78. 196 c.c.
79. (*a*) H : 1,000 cu. ft.
    (*b*) O : 500 cu. ft.
80. (*a*) CO : 500 cu. ft.
    (*b*) H : 500 cu. ft.
81. 200,000
82. 1,800 c.c.
83. (*a*) N : 1,000,000
    (*b*) H : 3,000,000
84. 2,000 c.c.
85. 20.22%
86. (*a*) CO_2 : 550 cu. ft.
    (*b*) H_2O : 1,340 cu. ft.
87. 15,175 cu. ft.
88. (*a*) 2 liters.
    (*b*) H : .5 liters.
89. 1,190.5 cu. m.
90. (*a*) 595,238.1 cu. ft.
    (*b*) 200,000 cu. ft.
91. (*a*) 9
    (*b*) 8.5
    (*c*) 14
    (*d*) 15
    (*e*) 22
92. (*a*) 76
    (*b*) 17
93. (*a*) 3.24 g.
    (*b*) 296

94. (*a*) 8 : 39
  (*b*) 10 liters.
95. (*a*) (i) 14
  (ii) .97
  (*b*) 70.8
96. (*a*) 84 l.
  (*b*) 758.93 g.
97. (*a*) 71 g.
  (*b*) 28 g.
  (*c*) 64 g.
  (*d*) 81 g.
  (*e*) 16 g.
98. (*a*) 9.6 l.
  (*b*) 168 l.
  (*c*) 15.77 l.
  (*d*) 16 l.
  (*e*) 80 l.
99. 27.43 l.
100. 2,240 c.c.
101. 14.93 l.
102. 357.14 g.
103. 224 cu. m.
104. 502.23 lb.
105. 13.44 l.
106. 2.95 g.
107. (*a*) CO : 3.73 l.
  (*b*) CO_2 : 3.73 l.
108. (*a*) CO : 44,800 cu. ft.
  (*b*) H : 44,800 cu. ft.
109. 140 cu. m.
110. (*a*) CO_2 : 2.49 l.
  (*b*) N : .83 l.
111. 58.83 c.c.
112. 2.34 l.
113. 1.19 c.c. less.
114. .95 c.c.
  New vol.: 28.45 c.c.
115. 208°.8 C.
116. 62.32 c.c.
117. 2.67 l.
118. 26 cm.
119. 731.4 mm.
120. 40 cu. ft.
121. 450 lb.
122. 20 times.
123. 1,950 cu. ft.
124. 3.17 cm. higher.
125. 4.8 in. higher.
126. 57.28 c.c.
127. 2.49 l.
128. 33.33 cm.
129. 73.89 c.c.
130. 2.94 l.
131. (*a*) 11.20 l.
  (*b*) 12.18 l.
132. 779.49 c.c.
133. (*a*) 73.42 l.
  (*b*) 6.55 g.
134. 53.66 l.
135. 6.06 l.
136. 22.82 c.c.
137. 1.70 l.
138. .0038 g.
139. 259.55 cm.
140. 65.8
141. 390.6 lb.
142. 741.57 mm.
143. 20.5%
144. 24°.6 C.
145. 126.26 c.c.
146. 26.53 g.
147. 3.52 g.
148. 4.58 g.
149. 1.55 g.

150. 3.15 g.
151. 40.83 g.
152. 1.83 g.
153. (*a*) 126.58 g.
  (*b*) 28.35 l.
154. (*a*) 18,119.66 lb.
  (*b*) 122,530 cu. ft.
155. 2,960 lb.
156. 2.5 kilos.
157. (*a*) 10.09 kilos.
  (*b*) 2.38 l.
158. 58.82 g.
159. 25.98 g.
160. 53.8 g.
161. 1,462.5 g.
162. 31.4 l.
163. 31.2 g.
164. 4.85 g.
165. 2,962.96 lb.
166. 1.1
167. 70 c.c.
168. 2.5
169. 1.56
170. (*a*) 500 c.c.
  (*b*) 500 c.c.
171. 1.168
172. 21.92 l.
173. 1.08
174. 9.25
175. 3.9
176. 1,284.31 g.
177. 159.47 g.
178. 267.17 c.c.
179. 287.66 g.
180. 28.48%
181. (*a*) 220 g.
  (*b*) 135.01 l.
182. 194.34 l.
183. 27.86 c.c.
184. 43.68 l.
185. (*a*) 64.34 c.c.
  (*b*) 23.47 c.c.
186. $Al_2O_3 \cdot H_2O$
187. Na_3AlF_6
188. U_3O_8
189. $CaCO_3$
190. Cu_2S
191. $MgO \cdot H_2O$
192. Zn_2SiO_4
193. $2Fe_2O_3 \cdot 3H_2O$
194. $Al_2SiO_4F_2$
195. C_2H_4
196. C_2H_2
197. $C_2H_4Cl_2$
198. C_2Cl_3OH
199. $COCl_2$
200. C_5H_{12}
201. HCN
202. C_6H_6
203. $HgCl_2$
204. H_2S
205. (*a*) NO
  (*b*) N_2O_2
206. (*a*) 2
  (*b*) Cl_2
207. ———
208. ———
209. (*a*) A
  (*b*) Zn
210. (*a*) 4
  (*b*) 75
211. Hg
212. (*a*) 1
  (*b*) He

213. O_3
214. (*a*) 2
(*b*) S_8
215. P_4
216. (*a*) 133
(*b*) 200
(*c*) 59
(*d*) 116
(*e*) 55
217. (*a*) 9
(*b*) 29
(*c*) 3
218. (*a*) 32.5
(*b*) 68.1
(*c*) 2
219. 87.3
220. 58.6
221. 14
222. 35.5
223. 12
224. 198.2
225. 14
226. 108
227. 181.8
228. 200.7
229. 39.98
230. (*a*) 119
(*b*) 4
231. (*a*) .00068 g.
(*b*) 587.52 g.
232. 73,013.4 coulombs.
233. (*a*) .0001456 g.
(*b*) .0003028 g.
234. 852.77 g.
235. 7.2 g.
236. (*a*) 7.10 g.
(*b*) 7.33 g.
(*c*) 14.69 g.
237. (*a*) .157 g.
(*b*) 1.26 g.
(*c*) 10.34 g.
238. (*a*) 9.43 g.
(*b*) 5.02 g.
(*c*) 7.67 g.
239. 2.82 g.
240. 42.22 amperes.
241. (*a*) 6.3 g.
(*b*) N/2
242. .3257 g.
243. 84 g.
244. 11.2 g.
245. 3.25 g.
246. 4.9 g. to a l.
247. 15 c.c.
248. 5.64 g.
249. 94.44%
250. .5261 g.
251. .5284 g.
252. 96%
253. 91.87%
254. 1.275 c.c.
255. 99.11%
256. 87.60%
257. .00515 g.
258. (*a*) 15.66 c.c.
(*b*) 1.566 c.c.
259. 210 c.c.
260. (*a*) 4.95 g.
(*b*) 63.5 g.
261. (*a*) 1,089,500 " Cals."
(*b*) 303,000 " Cals."
262. 279,500 " Cals."
263. 38,000 " cals."
264. — 41,400 " Cals."
265. 37,700 " Cals."
266. 13,400 " Cals."

267. 96,900 “ Cals.”
268. (*a*) 17,400 “ Cals.”
(*b*) Heat of solution.
269. 2,400 “ cals.,” with H_2SO_4
270. 15,700 “Cals.”

271. (*a*) 63.64 sq. cm.
(*b*) 14.14 cm.
272. (*a*) 2,217.75 c.c.
(*b*) 226.80 g.
273. (i) 58.5
(ii) 62
(iii) 249.5
274. (i) H : 1.59%
N : 22.22%
O : 76.19%
(ii) Fe : 46.67%
S : 53.33%
275. (*a*) 892.86 tons.
(*b*) 148.75 g.
276. 15.90 g.
277. (*a*) 806° F.
(*b*) 4°.4 C.
278. 2,400 kilos.
279. (*a*) .13704
(*b*) .3424
280. 67.55%
281. 15
282. (*a*) 336.0 l.
(*b*) 354.46 l.
283. 60.57 g.
284. (*a*) 17
(*b*) 15,000 c.c.
285. 47°.1 C.
286. 25.76 g.
287. (*a*) .97
(*b*) 14
(*c*) .875
288. 19.65 g.
289. 750 cu. ft.
290. 148.02 cm.
291. 40
292. (*a*) 1.291 g.
(*b*) 3.214 g.
293. (i) 2.675 g.
(ii) 4.2875 g.
(iii) 6.20 g.
294. (*a*) CH_2O
(*b*) C_3H_8
295. .005495 g.
296. 61,071.43 “ Cals.”
297. 144.82 l.
298. 112 cu. ft.
299. (*a*) 84.21 lb.
(*b*) KNO_3 : 375 lb.
S : 55 lb.
C : 70 lb.
300. (*a*) 12.90 g.
(*b*) 11.45 l.
301. (*a*) 160 l.
(*b*) 314.29 g.
302. (*a*) 1,892.48 c.c.
(*b*) 214,000 g.
(*c*) 78.57 sq. cm.
303. (*a*) 792.86 lb.
(*b*) 1,068.75 kilos.
304. (*a*) 303° C.
(*b*) 4
305. 328.42 l.
306. 2
307. 1,628 lb.
308. 1,429.51 c.c.
309. (*a*) 172.8 g.
(*b*) 17.01 g.
310. 5,840 g.
311. 21.90%

312. 50%
313. 4.01 g.
314. 726.99 c.c.
315. 9.21 g.
316. HCl : 25.2 c.c.
Cl : 8.4 c.c.
317. 72,900 " cals."
318. 15.6 c.c.
319. 1,287.5 g.
320. 79.92
321. (*a*) 100.27 kilos.
(*b*) 35.09 cu. m.
322. (*a*) 67.86%
(*b*) 20%
323. 9.5 g.
324. (*a*) 87.99%
(*b*) 94.07%
325. (*a*) 2.35 g.
(*b*) 23.36 g.
326. 7
327. 26.88 l.
328. (*a*) .0803 g.
(*b*) .3426
329. (*a*) 5.30 g.
(*b*) 20.86%
330. (*a*) H : n
O : n/2
(*b*) O_3
331. (*a*) Bi_2O_3
(*b*) $FeAs_2$
332. 631.89 kilos.
333. 20 cm.
334. 59
335. 6.16%
336. 19.07 atmospheres.
337. (*a*) 1.24
(*b*) 2,745 g.
338. 8,036.80 cu. ft.
339. (i) 182.14 lb.
(ii) 638.46 lb.
(iii) 200.00 lb.
340. (*a*) 20 kilos.
(*b*) 7.57 cu. m.
341. 3.70 as great.
342. 12 c.c.
343. .17 g.
344. (*a*) 3.45
(*b*) R_4
345. 705.6 c.c.
346. 36.61 g.
347. (*a*) 39.18%
(*b*) 3
348. 981.71 kilos.
349. 9.50 atmospheres.
350. 31.23%
351. CuO
352. 37%
353. 40%
354. 68.83%
355. (*a*) 2.14
(*b*) 68.04 kilos.
356. 58.71 g.
357. 39.1
358. 4.0 g.
359. .10825 g.
360. N_2O_3
361. 11,504.35 g.
362. 1,800 " cals."
363. (*a*) 125.9
(*b*) I_2
364. (*a*) 2,646.28 cu. m.
(*b*) 1,072.82 cu. m.
365. 25.56 kilos.
366. .265%

367. 6.97
368. 1,419.47 l.
369. 7.31 g.
370. $C_4H_{10}O$
371. (*a*) 1,776.22 lb.
(*b*) (i) C : 42.86%
O : 57.14%
(ii) N : 40.00%
O : 45.71%
H : 14.29%
(iii) Na : 12.04%
B : 11.52%
O : 29.32%
H_2O : 47.12%
372. 4,032.26 c.c.
373. .24%
374. (*a*) 466.28 g.
(*b*) 13.40 g.
375. 13.93 g.
376. 9.465 cu. m.
377. (*a*) .00214 g.
(*b*) .01%
378. (*a*) .01097 g.
(*b*) 63.30%
379. 4,404.85 cu. ft.
380. 5/6 of orig. vol.
381. 4.88 l.
382. 1.31 g.
383. (*a*) 565.15 g.
(*b*) 744.67 l.
384. (*a*) 11 : 40
(*b*) 1 : 5
385. 1,714,285.7 "cals."
386. .76 g.
387. (*a*) (i) 1.24 l.
(ii) .62 l.
(*b*) 1.70 l.
388. CO_2 : 28 l.
SO_2 : 7 l.
389. (*a*) 57.2 g.
(*b*) 4.80 l.
390. (*a*) 7 g.
(*b*) 81.9 kilos.
391. (*a*) 107.90
(*b*) 137.21
392. 121.25 l.
393. (*a*) .173 g.
(*b*) 40.11 c.c.
394. 72°.6 C.
395. 652.04 g.
396. 1,716.22 lb.
397. .0020625 g.
398. 55,253.33 cu. ft.
399. 387.35 kilos.
400. 26.1 g.

APPROXIMATE ATOMIC WEIGHTS FOR CALCULATION

(Adapted from the International Atomic Weights of 1913)

Name	*Symbol*	*At. wt.*
Aluminum	Al	27
Antimony	Sb	120
Argon	A	40

Name	*Symbol*	*At. wt.*
Arsenic	As	75
Barium	Ba	137.5
Bismuth	Bi	208
Boron	B	11
Bromine	Br	80
Cadmium	Cd	112.5
Caesium	Cs	133
Calcium	Ca	40
Carbon	C	12
Cerium	Ce	140
Chlorine	Cl	35.5
Chromium	Cr	52
Cobalt	Co	59
Copper	Cu	63.5
Fluorine	F	19
Gold	Au	197
Helium	He	4
Hydrogen	H	1
Indium	In	115
Iodine	I	127
Iridium	Ir	193
Iron	Fe	56
Krypton	Kr	83
Lead	Pb	207
Lithium	Li	7
Magnesium	Mg	24.5
Manganese	Mn	55
Mercury	Hg	200.5
Molybdenum	Mo	96
Neon	Ne	20
Nickel	Ni	58.5
Nitrogen	N	14
Osmium	Os	191
Oxygen	O	16
Palladium	Pd	107
Phosphorus	P	31

Name	*Symbol*	*At. wt.*
Platinum	Pt	195
Potassium	K	39
Radium	Ra	226.5
Rhodium	Rh	103
Rubidium	Rb	85.5
Samarium	Sm	150.5
Scandium	Sc	44
Selenium	Se	79
Silicon	Si	28.5
Silver	Ag	108
Sodium	Na	23
Strontium	Sr	87.5
Sulphur	S	32
Tantalum	Ta	181.5
Tellurium	Te	127.5
Thallium	Tl	204
Thorium	Th	232.5
Tin	Sn	119
Titanium	Ti	48
Tungsten	W	184
Uranium	U	238.5
Vanadium	V	51
Xenon	Xe	130
Yttrium	Yt	89
Zinc	Zn	65.5
Zirconium	Zr	90.5

METRIC SYSTEM AND EQUIVALENTS

1 inch = 25.4 mm. = 2.54 cm.
39.37 inches = 1000 mm. = 100 cm. = 10 dm. = 1 meter.
1 foot = 304.8 mm. = 30.48 cm. = 3.048 dm. = .3048 meters.
1 mile = 1609.31 meters = 1.60931 kilometers.
1 sq. in. = 6.4514 sq. cm.
1 cu. in. = 16.386 cu. cm. or c.c.

1 U. S. Standard Gallon = 4 qt. = 231 cu. in. = 3.785 liters.

1 U. S. fluid ounce = 29.57 c.c.

1 lb. Avoirdupois = 453.6 grams.

1 oz. Avoirdupois = 28.35 grams.

1 kilometer = 1000 meters = .6214 mile.

1 c.c. = .0338 U. S. fluid oz.

1 c.c. = .2704 fl. dr.

1 gram = 15.432 grains.

1 kilogram = 2.2046 lb.

1000 liters = 1000 cu. dm. = 1 cu. meter = 35.31 cu. ft.

1 liter = 1000 c.c. of water (distilled) at 4° C. weighs 1000 grams = 1 kilogram = 1.0567 qts.

1000 kilograms = 1 metric ton = 2204.6 lb.

1000 liters = 1 cu. meter of water at 4° C. weighs 1000 kilograms.

1 c.c. of water at 4° C. weighs 1 gram.

ARITHMETICAL UNITS

Area of circle $= \pi r^2$ (where $\pi = 22/7$)

Circum. of circle $= 2\pi r$

Area of surface of sphere $= 4\pi r^2$

Volume of sphere $= 4/3\pi r^3$

Vol. of cylinder = area of base x height $= \pi r^2 h$

Surface of cylinder = circum. of base x height $= 2\pi r h$

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1 mile = 5280 ft.

1 ton = 2000 lb.

1 cu. ft. of water weighs 62.5 lbs.

VAPOR TENSION OF WATER

0 to 100° C.

(Adapted from Regnault and Broch)

Temp. C.°	Pressure in mm.	Temp. C.°	Pressure in mm.	Temp. C.°	Pressure in mm.
0	4.6	21	18.5	59	142.4
0.5	4.7	21.5	19.0	60	149.2
1	4.9	22	19.6	61	156.3
1.5	5.1	22.5	20.2	62	163.6
2	5.3	23	20.9	63	171.3
2.5	5.5	23.5	21.5	64	179.2
3	5.7	24	22.2	65	187.5
3.5	5.9	24.5	22.8	66	196.1
4	6.1	25	23.5	67	205.0
4.5	6.3	25.5	24.2	68	214.2
5	6.5	26	25.0	69	223.8
5.5	6.7	27	26.5	70	233.8
6	7.0	28	28.1	71	244.1
6.5	7.2	29	29.8	72	254.8
7	7.5	30	31.5	73	265.9
7.5	7.7	31	33.4	74	277.4
8	8.0	32	35.3	75	289.3
8.5	8.3	33	37.4	76	301.6
9	8.6	34	39.6	77	314.4
9.5	8.9	35	41.8	78	327.6
10	9.2	36	44.2	79	341.3
10.5	9.5	37	46.7	80	355.5
11	9.8	38	49.3	81	370.1
11.5	10.1	39	52.1	82	385.2
12	10.5	40	54.9	83	400.9
12.5	10.8	41	58.0	84	417.1
13	11.2	42	61.1	85	433.8
13.5	11.5	43	64.4	86	451.1
14	11.9	44	67.9	87	468.9
14.5	12.3	45	71.5	88	487.3
15	12.7	46	75.3	89	506.4
15.5	13.1	47	79.2	90	526.0
16	13.6	48	83.3	91	546.3
16.5	14.0	49	87.6	92	567.2
17	14.4	50	92.1	93	588.8
17.5	14.9	51	96.8	94	611.0
18	15.3	52	101.7	95	634.0
18.5	15.8	53	106.9	96	657.7
19	16.4	54	112.2	97	682.1
19.5	16.9	55	117.7	98	707.3
20	17.4	56	123.5	99	733.2
20.5	17.9	57	129.6	100	760.0
		58	135.9		